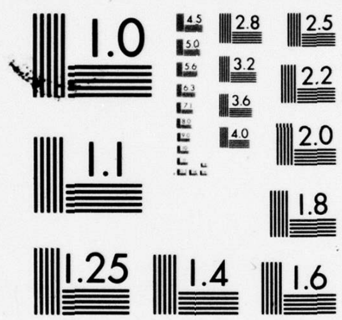
AD-A071 840 WYLE LABS HUNTSVILLE ALA F/G 13/10
DEFINITION AND CLASSIFICATION OF NATURAL AND INDUCED ENVIRONMEN--ETC(U)
SEP 78 DOT-CG-40672-A
UNCLASSIFIED MSR-78-12 USCG-D-20-79 NL

1 OF 3
AD
A071840


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

Report No. CG-D-20-79

6
B.S.

LEVEL II

DEFINITION AND CLASSIFICATION OF NATURAL AND INDUCED ENVIRONMENTS OF SOME RECREATIONAL BOATS

SEPTEMBER 1978

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22151

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20590

3¼" to trim

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

292-531 Cov. 2

S/S Cov 3-4- blanks

Cover (2)

3+4X

19 18 USCG

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-20-79		

4. Title and Subtitle	5. Report Date
6 DEFINITION AND CLASSIFICATION OF NATURAL AND INDUCED ENVIRONMENTS OF SOME RECREATIONAL BOATS .	11 Sep[redacted]78
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s) Wyle Laboratories	14 MSR-78-12
9. Performing Organization Name and Address Wyle Laboratories, P.O. Box 1008, Huntsville, Alabama 35807	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. 15 DOT-CG-40672-A
12. Sponsoring Agency Name and Address Department of Transportation, United States Coast Guard, Office of Research and Development, Washington, D.C. 20590	13. Type of Report and Period Covered 9 Final Report 10 Apr[redacted]75 - Nove[redacted]76.
	14. Sponsoring Agency Code USCG (G-DSA)

15. Supplementary Notes

12 287p.

16. Abstract

The objective of this work was to examine some of the environmental problems associated with boats and subsystems (equipment), to experiment with test methods, test equipment, data retrieval equipment, and data reduction techniques. A literature search was performed, methods have been tested, some problems have been uncovered and solved, and some test data on noise, and shock/vibration have been retrieved, reduced, and analyzed on small boats and larger yachts. The results and conclusions from this work are summarized in Section I of this report. Sections II through V and Appendices A and B present the results of work on the literature survey, subsystems environment classifications, acquired induced environment data for 1974 and 1975, and acoustic data. Section VI presents a discussion of what is needed as a next phase toward the derivation of a subsystems environmental manual for recreational boats. Appendix C is an addendum to Section VI and discusses failure physics and environmental stressors.

405 950 Gu

17. Key Words	18. Distribution Statement
Subsystems, Recreational Boats, Induced Environment, Natural Environment, Boat Noise	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	286	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

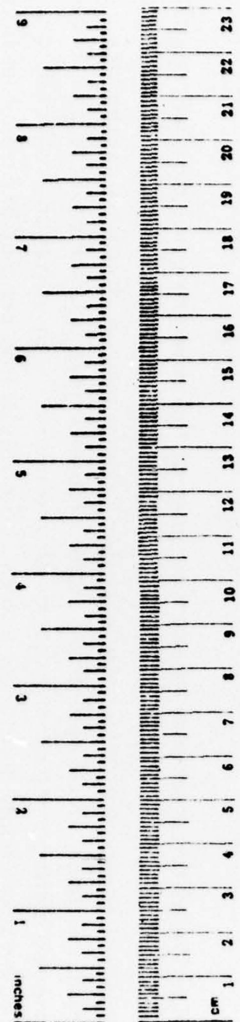
90% 292-531 (1)

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

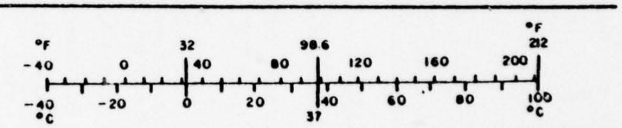
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



90%

292-531 (2)

(2)

TABLE OF CONTENTS

Short all S/S except indicated 292-531 3

3

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (concluded)

ERRATA

1. Page 40, line 6- "Is is" should read "It is."

2. Page 65 should read "Figure IV-4 Boat Instrumentation Package."

3. Page 66 should read "Figure IV-3 Stern Accelerometer Installation."

4. Page 67 should read "Figure IV-2 Amidships Accelerometer Installation."

5. Page 68 should read "Figure IV-1 Bow Accelerometer Installation."

6. Page 70 second bullet second line "on the following page" should read "below."

7. Page 76 last line delete "instrumental."

8. Page 83 Section 5.3 line 7 "realtive" should read "relative."

9. Page 97-98 Section 7-2. Caution should be exercized in the interpretation of the derivation and accompanying discussion due to the following comments:

a). The kinematic equation v=at is usually applicable only with constant acceleration. The variable shock accelerations do not conform to this definition.

b). The equation, area=at, should more properly be written, area=$\int adt$ for this type of analysis.

c). The area of a triangle is given as area=1/2xbasexheight.

d). A clear definition of effective mass for this analysis is not present.

10. Page 101-102, Section 7.3. Caution should be exercized in the interpretation of the derivation and accompanying discussions due to the following comments:

a). Equation (1) should read $\ddot{x}+2w_n\dot{x}+w_n^2x=F(t)$.

b). Parenthesis should be included in equation (2) to separate the initial conditions.

c). Initial conditions for equation 3 should read "$\dot{x}_o=x_o=0$."

d). The use of ∅ in equation (4) is not defined.

e). The arrangement and derivation of equations (3) to (5) does not conform to accepted practice.

11. Page 119, third bullet. The meaning and significance of Ee/K is not clear and caution should be exercized in the use of this information.

12. Page A-2. "Founding" should read "Pounding."

SECTION I - INTRODUCTION AND SUMMARY

1.0 INTRODUCTORY SUMMARY

The work described herein was directed toward the identification of the environment within which subsystems of a typical recreational boat must operate. Independent, and seemingly disparate efforts, were undertaken to investigate this environmental phenomenon, and this document, entitled "Definition and Classification of Natural and Induced Environments of Some Recreational Boats," has been developed to tie together and present under one cover the results of these diverse efforts. In addition to providing rudimentary information on boat/subsystems operational environments, it is felt that this document will usefully serve as a source of threshold data and direction for the development of a practical and useful boat/subsystems environment manual.

This report is divided into six main sections in addition to the Appendices.

- The remainder of Section I of this document summarizes the main sections and provides a cursory review of the parameters, constraints and results of the directed work effort.

- Section II - Literature Survey of Existing Environmental Data, delineates the literature examined and defines its applicability and usefulness to the overall program purpose.

- Section III - Subsystems Environment-Classification and Specification, documents the rationale, interrelationships, and supporting considerations leading to the detailed identification and classification of boats, subsystems, and environmental parameters which are also documented within Section III.

- Section IV - Acquired Induced Environment Data for 1974 and 1975, presents the operational data collected during two live boat experiments. Instrumentation, collection methods, analysis/reduction techniques, comparison with "other" experiments, and recommendations are also discussed.

- Section V - Presently Available Acoustic Environmental Data, summarizes available data on water, wind and engine noise; and presents the results of a variety of experiments performed by Wyle and others which lead to further questions regarding experimental conclusions.

- Section VI - Expanded Induced Environmental Data Acquisition Program, presents a methodology and specific approach for acquiring baseline environmental data prerequisite to developing a meaningful subsystems environment manual.

2.0 LITERATURE SURVEY OF EXISTING ENVIRONMENTAL DATA

Since the beginning of the boating safety program authorized by the Federal Boat Safety Act of 1971, it has been recognized that a need exists to identify the environment to which recreational boats are exposed. To this recognized need, literature research to centralize available data was undertaken.

This search was conducted utilizing four major sources:

- Shock and Vibration Bulletin (1957-73),
- Journal of Environmental Science (1959-69),
- Existing Military Specifications (MIL-STD-810B),
- American Society of testing and Materials (ASTM) Standards, and,

in addition, Wyle's El Segundo Research Staff's published measured data on outboard engine noise for the Environmental Protection Agency.

The results of the literature search have led to the following conclusions (see Section II):

- The majority of existing environmental data cannot be used nor extrapolated for defining subsystems environment.
- Further evaluation is required on existing natural environmental data to establish suitable criteria which are compatible to boating operations.
- Further effort is required to acquire and to compile usable, induced environmental data applicable to the definition of combined subsystem environments.

3.0 SUBSYSTEMS ENVIRONMENT — CLASSIFICATION SUMMARY

Boat classifications are necessary as the environment will be different for a 14 ft (4.3 m) aluminum johnboat compared to a 36 ft (11 m) cabin cruiser. Environment classifications are of two types, natural and induced. Natural environment in general is related to geographical location; induced environment is that related to the movement of the boat either during transportation or normal use.

3.1 Boat Classifications

Several boat characteristics were considered in order to determine possible boat classifications. A reasonable class is one that will contain a sufficient number of boats to produce meaningful data. A tentative set of characteristics that enable the establishment of "reasonable classes" is the following:

- Propulsion system - Outboard, inboard/outdrive, water jet
- Length - Equal to or less than 16 ft (4.9 m)
  - Equal to or less than 26 ft (7.9 m), but greater than 16 ft (4.9 m)
  - Greater than 26 ft (7.9 m)
- Hull design - Flat bottom, deep-V, cathedral
- Hull material - Fiberglass, metal, wood

Data from the Nationwide Boating Survey (Reference 1) indicate that the two most popular recreational boats are the single engine outboards less than 16 ft (4.9 m) and the single engine I/Os between 17 and 26 ft (5.2 and 7.9 m). Boating industry data determined by motor sales indicate the ratio of engine types (outboard, inboard/outdrive, water jet) is 100/10/1.

3.2 Natural Environmental Factors

Natural environmental factors affect boat subsystems producing deterioration and aging whether or not the boat is in operation. The effects of these factors are functions of time and

intensity. Natural environmental factors consist of the following:

- Temperature
- Sunlight
- Rain
- Humidity
- Salt spray
- Sand/Dust

3.2.1 Natural Environmental Factor Specifications

At present there exists more data for the specification of natural environmental factors of recreational boats than induced environments, since climatic statistics have been compiled over a long period of time and are readily available.

Temperature, Precipitation, Sunshine and Humidity — Figures III-4 through III-9 of Section III depict available data on the following natural environments:

- Mean monthly average temperature
- Mean monthly minimum temperature
- Mean monthly maximum temperature
- Mean annual precipitation
- Monthly precipitation means and extremes
- Mean annual sunshine - Environmental data on monthly sunshine and relative humidity is also available.

3.3 Induced Environmental Factors

Induced environmental factors result from the motion of the boat during operation or while being transported. These induced environmental factors are acceleration, noise, and shock/vibration.

3.3.1 Induced Environmental Factors Specifications

Specifications for acceleration, noise, and shock/vibration are presented in Sections IV and V. A summary of results is provided as follows:

- Lateral acceleration - Lateral acceleration of the center of mass of relatively small boats (up to 18 ft (5.5 m) in length) indicate peak values of 1.5 - 2.0 g in emergency maneuvers with average values for sudden maneuvers of 0.8 - 1.2 g. It can be expected that larger boats would have values decreasing from the above as boat length (and weight) increases (speed decreases).

- Noise - Wyle Laboratories recently measured the sound levels at the operator's position on eleven boats. Results are shown in Figures V-4 and V-5 of Section V. Sound levels were measured at idle or 1000 rpm, at a comfortable cruising speed, and at full throttle. Average values are shown below:

Condition	Speed (mph)	Sound Level (dBA)
Idle	6.2	69.1
Cruise	25.4	82.2
Full Throttle	35.6	90.6

  If 73 dBA background noise is considered the upper limit for reliable speech communication while shouting, then reliable speech communication is impossible when running at cruising speed or faster.

- Shock/Vibration - Information obtained from shock analysis was not conclusive. Spectra for all events appeared to fall off around 800 to 900 Hz. Since this was near the edge of the frequency band for analysis, significance should not be attributed to it without further investigation. Results from data obtained show a spectra envelope depicted in Figure I-1 for bow and stern locations. It is expected that a difference in spectra from different boats should be seen, but this conclusion can be drawn only with more data.

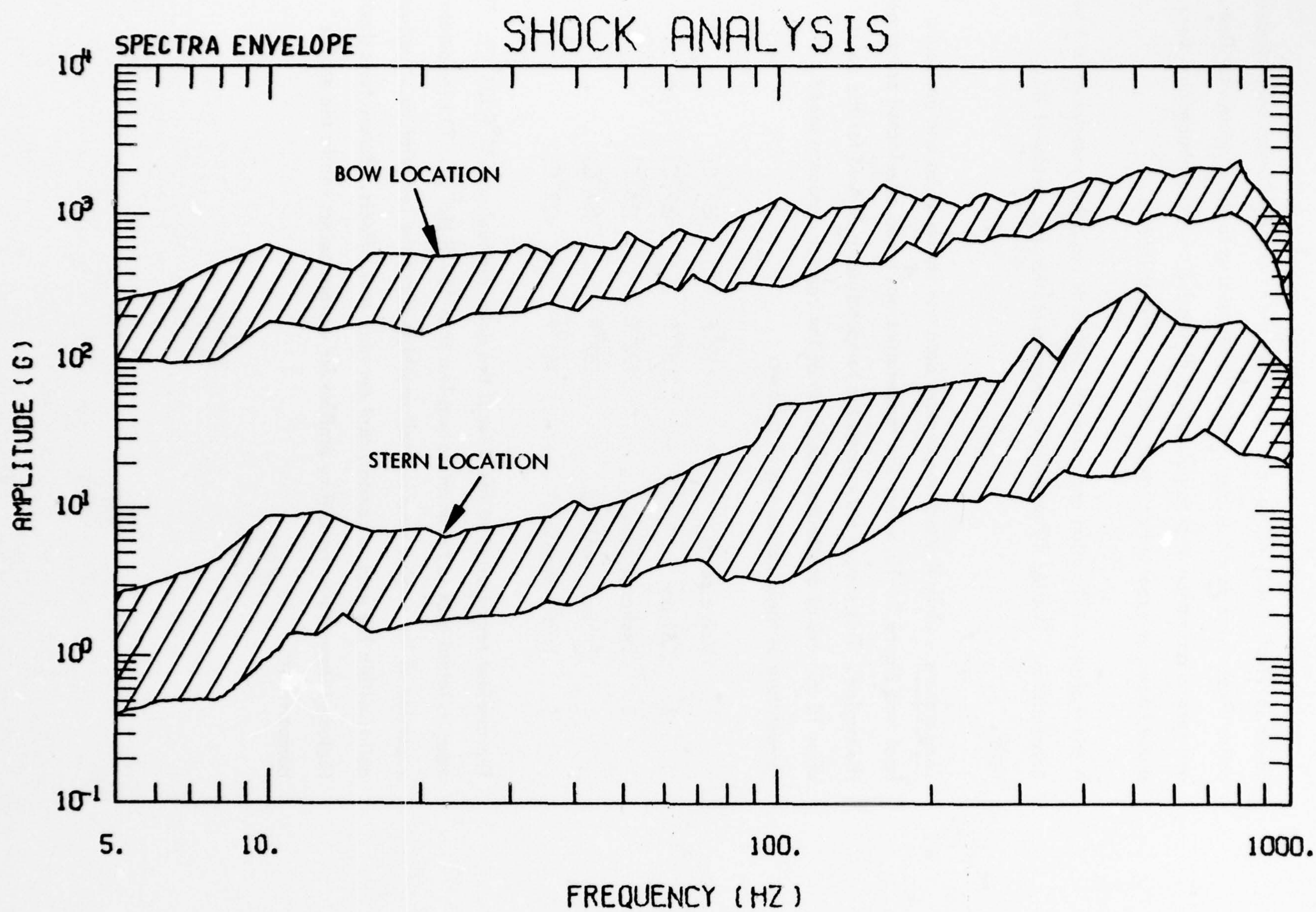


FIGURE I-1. SHOCK ANALYSIS ENVELOPES

292-531 (13)

(13)

Power spectral density analysis on stationary data indicated broad band random data. Peaks were found at frequencies corresponding to the fundamental first and second resonance of prop pulses (see Figure I-2). These frequencies were shifted down as expected at lower engine speed settings.

A study of shock/vibration and noise environments has been undertaken at Wyle Laboratories. Section IV presents the documentation and results of this work.

- Temperature - Only limited temperature data was retrieved on one particular boat (see Figure IV-13) where the temperature was taken at selected points on the engine. This sample only shows the temperatures achieved for the points after 15 minutes of continuous operation of the boat at maximum speed. The temperature at these points was as follows:

1.	Valve cover	-	152°F	(67°C)
2.	Oil pan	-	157°F	(69°C)
3.	Exchange riser	-	122°F	(50°C)
4.	Exhaust manifold	-	152°F	(67°C)
5.	Intake manifold	-	161°F	(72°C)

The ambient temperature at the time of the data retrieval was 78°F (26°C). The mean external engine temperature was less than 150°F (66°C). The temperature excursion of the engine does not tell anything about the temperature at various points within the engine compartment nor heat soak effects. Future tests should include temperature versus time profiles for various points within the engine compartment.

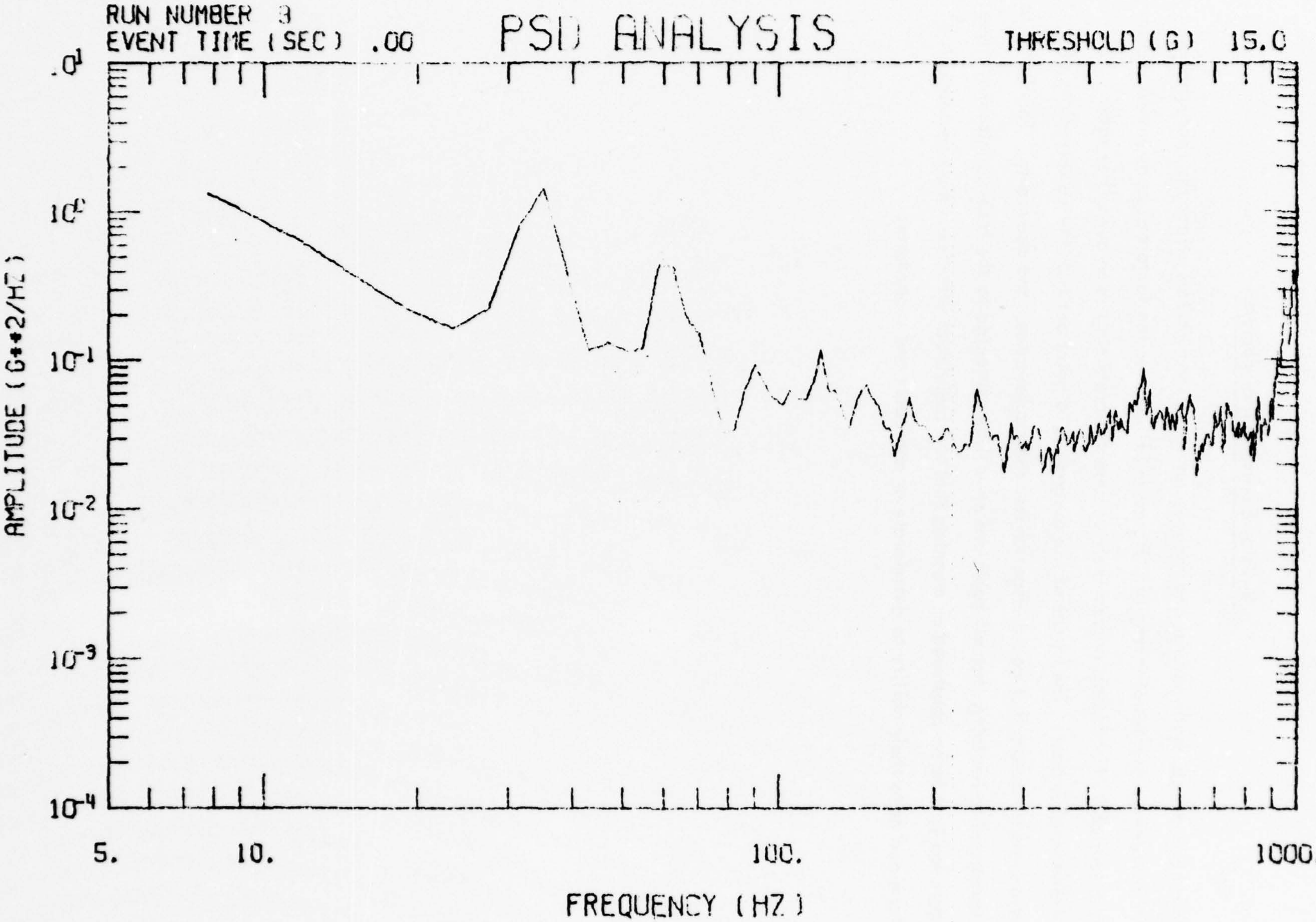


FIGURE I-2. PSD ANALYSIS

3.4 Total Environmental Factors

As has been stated, both natural and induced environmental factors affect the recreational boats to varying degrees of intensity. Figure I-3 illustrates the factors of both environments that potentially affect boats and/or their occupants, producing some overall or total environmental impact. The intent of the diagram is to point out that the combinations of environmental factors that could affect boats, their subsystems, and occupants. This is not to be construed as implying that all boats are or will be subjected to the total spectrum of these factors nor is it to be construed as meaning that the individual effects of these factors can be determined as to their ability to deteriorate or age boats and subsystems.

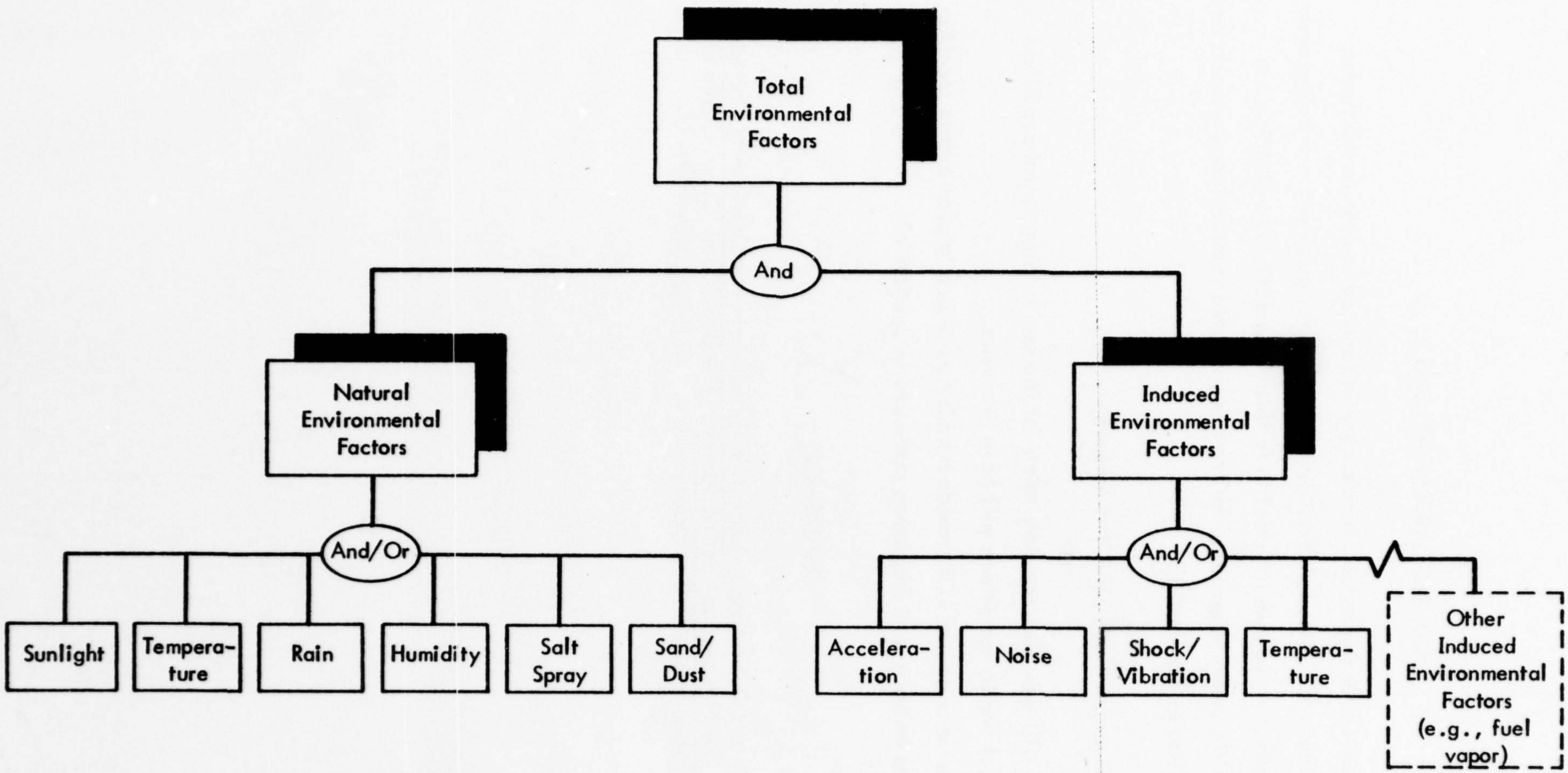


FIGURE I-3. TOTAL ENVIRONMENTAL FACTORS POTENTIALLY AFFECTING BOAT SUBSYSTEMS

90%

292-531

17

4.0 RECOMMENDATIONS

As is indicated by the sections of this report, a data bank of induced environmental factors data is limited in scope and usefulness, but does serve as a basis for guiding the planning and development of future work. A program intended to further expand the data planning and retrieval effort into specific useful information for the designers and manufacturers of boats and their subsystems is described in Section VI.

The results of this present program will serve two purposes:

- The data will provide some data points for induced environmental conditions that a boat and its subsystems will have to endure.
- The experience gained will provide a basis from which to plan a more specific subsystems measurement program as presented in Section VI.

REFERENCES

1. Wulfsberg, R.M. and D.A. Lang. Recreational Boating in the Continental United States in 1973: The Nationwide Boating Survey. The U.S. Coast Guard Office of Boating Safety, Washington, D.C. October 1974. NTIS No. AD-A000-471.

5/5 292-531 (18)

(18)

SECTION II –
LITERATURE SURVEY OF EXISTING ENVIRONMENTAL DATA

1.0 INTRODUCTION

Since the beginning of the boating safety program authorized by the Federal Boat Safety Act of 1971, it has been recognized that a need exists to identify the environment to which recreational boats are exposed. To this recognized need, literature research to centralize available data and on-going research to provide current data where necessary has been undertaken.

2.0 LITERATURE SURVEY

Environmental data are used to provide guidelines in engineering design. In general, structural and mechanical systems are designed to withstand both natural and induced environments for a specified life cycle. The natural environmental data are derived from regional meteorological data; and since natural environments induce various corrosive and deteriorating effects on materials, the compliance of design requirements in respect to specified natural environments is normally accomplished through laboratory and environmental testing. The performance of components to the induced environments of acceleration, shock and vibration can be verified in two ways. The first approach is to test a component to its specified environment and to evaluate the condition of the component during and at the end of the test period. The second approach is to evaluate the strength of components through mathematical analysis to determine the design safety factor.

This section summarizes the results of a literature survey on applicable data related to subsystems environment of small boats. The search was conducted on four major sources which consist of:

- Shock and Vibration Bulletin (1957-73)
- Journal of Environmental Science (1959-69)
- Existing Military Specifications (MIL-STD-810C)
- American Society for Testing and Materials (ASTM) Standards (1973-74)

The Coast Guard, through their collision research program, had obtained applicable acoustic (noise) data. In connection with that project's work, a literature search and survey was performed. Pertinent data/information developed during the collision research was combined with the relevant data gleaned from the literature and is presented in this report in Section V. Since the subject has been covered in considerable depth in Section V, it will not be summarized in this section. Also, references reviewed for acoustic study are presented at the end of Section V and not repeated in this section.

3.0 LITERATURE SURVEY EVALUATION AND CONCLUSIONS

In addition to the aforementioned major sources, the bibliography contains nearly fifty other articles and/or publications relating to environments, tests, and simulations that were reviewed for ideas for potential applications in the subsystems environment research.

The applicability of environmental criteria derived from the literature search is summarized in the following conclusions:

1. The bibliography contains several articles on transportation induced vibrations. Most of these pertain to specific studies relating to military equipment such as aircraft, missiles and various ground vehicles. It is Wyle's opinion that there are no feasible methods of extrapolating this type of information to the boat transportation problem with any degree of confidence. It is further felt that shock and vibration data for boats and subsystems could be obtained more accurately and more cost effectively by direct measurement rather than extrapolating data from other types of hardware systems.

2. No adequate techniques were found in the literature for deriving a combined environmental factors (natural and induced) impact that would be applicable for boats. However, with information obtained from boating operations surveys, measured environmental data for shock, vibration, acceleration, and noise, and meteorological data, combined or total boat environmental factors can be established for various boating operations. Such environments can be specified in cycles which define the type of natural and induced environments to be combined and length of time for which boats are to be operated.

3. The American Society for Testing and Materials (ASTM) Standards provide general test guidelines. While they do not have specific, direct applicability to the boat subsystem environment, they are valuable references that should be consulted when designing environmental tests for boats and susbystems.

4. MIL-STD-810C (March 10, 1975) contains various environmental test methods. With modifications, some could be applicable to boats and subsystems. Those with potential applicability are:

- Method 501.1 High Temperature
- Method 505.1 Solar Radiation (Sunshine)
- Method 506.1 Rain
- Method 507.1 Humidity
- Method 508.1 Fungus
- Method 509.1 Salt Fog
- Method 510.1 Dust (Fine Sand)
- Method 511.1 Explosive Atmosphere
- Method 512.1 Leakage (Immersion)
- Method 513.2 Acceleration
- Method 514.2 Vibration
- Method 515.2 Acoustical Noise
- Method 516.2 Shock

MIL-STD-810C describes general effects, procedures (alternative methods), apparatus, instrumentation, and miscellaneous other test specific items. While this document provides clear test procedures for the listed environments (and many others not applicable to the boat and/or subsystems), the undertaking of these types of tests in lieu of direct measurements from instrumented boats in actual operating conditions would be exhorbitant from both cost and time standpoints. Therefore, the application of MIL-STD-810C or some variation thereof for other than testing specific components of a boat subsystem, such as an engine, would not be feasible.

BIBLIOGRAPHY

American Standards for Testing Materials. "Materials Performance and the Deep Sea - STP 445." ASTM Publication. 1969.

American Society for Testing and Materials (ASTM) Standards. 1974:

(1) Volume 10, Erosion, Wear, and Fatigue
(2) Volume 11, Nondestructive Testing
(3) Volume 18, Acoustics, Environment
(4) Volume 28, Pigments, Resins, Polymers
(5) Volume 29, Fatty Oils and Acids, Solvents, Miscellaneous
(6) Volume 35, Plastics, General Test Methods
(7) Volume 41, Deterioration of Nonmetallic Materials

Barrowcliff, B.K. and R.E. Ehlert. "Full Scale Road Simulated Endurance Test." Society of Automotive Engineers. Report No. 680148. January 1968.

Bonvallet, Duane J. and Raymond D. Isaacson. "Laboratory Simulation of Vibration Environment Encountered in Rail Shipment of Automobiles." Society of Automotive Engineers. Report No. 690110. January 1969.

Carroll, J. "Impact of Transportation of Electronic Equipment." Institute of Environmental Sciences Proceedings, pp. 137-139. 1959.

Childs, W. "The Bump Testing of Military Signals Equipment in the United Kingdom." Shock and Vibration Bulletin 39, Part VI, p. 15.

Cripe, Ronald A. "Making a Road Simulator Simulate." Society of Automotive Engineers. Report No. 720095. January 1972.

Eustace, R.H. "Railroad Humping Testing on Units of the Pershing Weapon System." Institute of Environmental Sciences Proceedings, pp. 1-12. 1962.

Eustace, R. "Track-Vehicle Missile System Dynamic Environment Data Acquisition and Application." Shock and Vibration Bulletin 33, Part IV, p. 83.

Evans, L.B., H.E. Bass, and L.C. Sutherland. "Atmospheric Absorption of Sound: Theoretical Predictions." The Journal of the Acoustical Society of America, Vol. 51, No. 5 (Part 2), pp. 1565-1575. May 1972.

Foley, J.T. "Normal and Abnormal Dynamic Environments Encountered in Truck Transportation." Shock and Vibration Bulletin 39, Part VI, p. 31.

Foley, J.T. "Preliminary Analysis of Data Obtained in the Joint Army/AEC/Sandia Test of Truck Transport Environment." Shock and Vibration Bulletin 35, Part V, p. 57.

Francis, J.J. "Analytical and Experimental Evaluation of DD.692 Class Hull Vibration." Shock and Vibration Bulletin 35, Part VII, p. 119.

Gerdel, R.W. and G.H. Strom. "Scale Model Simulation of a Blowing Snow Environment." Institute of Environmental Sciences Proceedings, pp. 53-63. 1961.

Gibson, D. and J. Weinard. "Studies of the Spectral Energy Distribution of Different Light Sources in Connection with Solar Simulation." Institute of Environmental Sciences Proceedings, pp. 453-463. 1962.

Hager, R.W. and E.R. Conner. "Road Transport Dynamics." Shock and Vibration Bulletin 31, Part III, p. 102.

Harvey, J.R. and R.A. Wursche. "Roughness Measurement and System Response Evaluation for Highway Environment." Shock and Vibration Bulletin 35, Part V, p. 71.

Jaeckel, Henry R. and S.R. Swanson. "Predicting Service Life of Automotive Parts Calls for Random Load Test." Society of Automotive Engineers Journal, pp. 42-47. November 1969.

Junker, V.J. "The Evolution of USAF Environmental Testing." Flight Dynamics Laboratory, Wright-Patterson Air Force Base. Technical Report AFFDL-TR-65-197. October 1965.

Kasuba, J.A. "A Realistic Derivation of a Laboratory Vibration Test to Simulate the Overland Transportation Environment." Shock and Vibration Bulletin 35, Part V, p. 37.

Kennedy, R. "A Comparison of Shock and Vibration Data for Air, Rail, Sea and Highway." Shock and Vibration Bulletin 31, Part III, p. 81.

Kennedy, R. "Department of the Army Position on Transportation Environment Criteria." Shock and Vibration Bulletin 34, Part IV, p. 243.

Kennedy, R. "Railroad Transportability Criteria." Shock and Vibration Bulletin 40, Part VI, p. 85.

Kirshman, E.J. "Design Considerations for Rough-Road and Humping Specification Testing." Shock and Vibration Bulletin 26, Part II, p. 49.

Kruger, R. "Project Assess - A Report of a Long Term Solar Simulation Test." Institute of Environmental Sciences Proceedings, pp. 271-288. 1966.

Lahood, J.W. "Shock and Vibration Data Obtained from Truck and Rail Shipment." Shock and Vibration Bulletin 33, Part IV, p. 99.

Latzek, L.E. "Corrosion Problems Encountered in Silo Storage of Missiles." Institute of Environmental Sciences Proceedings, pp. 155-161. 1961.

Lee, C.B. "Fungal Deterioration of Materials in the Wet Tropical Environment of Panama." Institute of Environmental Sciences Proceedings, pp. 497-505. 1962.

Luebke, R.W. "The Box Car Dynamic Environment." Shock and Vibration Bulletin 41, Part IV, p. 141.

Mains, R.M. "Simulation of Shock and Vibration Environments." Institute of Environmental Sciences Proceedings, pp. 39-52. 1961.

Mallik, A.K. and A. Ghosh. "Improvement of Damping Capacity of Structural Members by Introduced Stress Concentration." American Society of Mechanical Engineers Publication, No. 73-DET-76. June 1973.

McCann, W.F. "Transportation Environments." Shock and Vibration Bulletin 34, Part IV, p. 259.

McCoy, H.E., W.R. Martin, and J.R. Weir. "Effect of Environment on the Mechanical Properties of Metals." Institute of Environmental Sciences Proceedings, pp. 163-176. 1961.

McKee, H.C. "Deterioration of Rubber in Northern Greenland." Institute of Environmental Sciences Proceedings, pp. 335-344. 1962.

Molinari, Louis A. and J.R. Reynolds. "Program 624A-TITAL III-C Transportation Tests." Shock and Vibration Bulletin 35, Part V, p. 87.

Military Standard - Environmental Test Methods. MIL-STD-810B, June 1967 and MIL-STD-810C, March 1975.

Montgomery, C.D. and B.D. Sissom. "U.S. Army Ordnance Automotive Environmental Testing Facilities." Shock and Vibration Bulletin 26, Vol. II, p. 61.

O'Dierna, Armand. "A Synergistic Six Degree of Freedom Motion System." AIAA Visual and Motion Simulation Technology Conference, Cape Canaveral, Florida. AIAA Paper No. 70-358. March 1970.

Ostrem, F.E. "Survey of the Cargo-Handling Shock and Vibration Environment." Shock and Vibration Bulletin 37, Part VII, p. 1.

Phillips, O.M. and M.L. Banner. "Wave Breaking in the Presence of Wind Drift and Swell." Journal of Fluid Mechanics (Great Britian), Vol. 66, Part 4, p. 625. 1974.

Pursifull, L.J. and B.E. Prothro. "Development of Railroad Roughness Indexing and Simulation Procedure." Shock and Vibration Bulletin 39, Part VI, p. 47.

Pursifull, L.J. "Problems Encountered in the Use of Instruments for Measuring Dynamic Environments." Shock and Vibration Bulletin 34, Part IV, p. 255.

Pursifull, L.J. "Shock and Vibration Environments Imposed by Current Transportation Media." Shock and Vibration Bulletin 26, Vol. II, p. 56.

Rice, J.E. "A Survey of Vibration Environment in Vehicles Traveling Over Paved Roads." Shock and Vibration Bulletin 33, Part IV, p. 95.

Rice, J.E. "Interpretation and Application of Specification Requirements that Simulate Vibration Responses of Equipment Being Shipped by Common Carrier." Shock and Vibration Bulletin 35, Part V, p. 129.

Schlue, J.W. and W.D. Phelps. "A New Look at Transportation Vibration Statistics." Shock and Vibration Bulletin 37, Part VII, p. 19.

Schock, R.W. and W.E. Paulson. "A Survey of Shock and Vibration Environments in the Four Major Modes of Transportation." Shock and Vibration Bulletin 35, Part V, p. 1.

Scialdone, J.J. "A Method for Estimating Accelerations of Shipping Containers Mounted on an Impacting Railroad Car." Shock and Vibration Bulletin 35, Part V, p. 49.

BIBLIOGRAPHY (Concluded)

Simmons, L.C. and R.H. Shackson. "Shock and Vibration on Railroad Movement of Freight." Shock and Vibration Bulletin 31, Part III, p. 94.

Simpson, M.H. "Simulation of Rain Environment." Institute of Environmental Sciences Proceedings, pp. 65-74. 1961.

Tinkham, E.I. "A Proposed Time Dependent Ambient Temperature Environment for Open Storage." Institute of Environmental Sciences Proceedings, Vol. I, pp. 23-28. 1967.

Vigness, I. "Elementary Considerations of Shock Spectra." Shock and Vibration Bulletin 34, Part III, p. 211.

West, Bruce J., Kenneth M. Watson, and J. Alex Thomson. "Mode Coupling Description of Ocean Wave Dynamics." The Physics of Fluids, Vol. 17, No. 6, p. 1059. June 1974.

Wyle Laboratories. "Phase I, Evaluation Report - Portable Plastic Fuel Tanks." Report No. 58209-1. September 1972.

SECTION III –

SUBSYSTEMS ENVIRONMENT – CLASSIFICATION AND SPECIFICATION

1.0 INTRODUCTION

In order to derive reasonable judgments about boats versus their environments, some logical attempt should be made to categorize the boats into classes based on common characteristics. It is readily apparent that there is a wide spectrum of boat types and that induced environmental factors are functions of these types. For example, the induced environmental factors identified with an aluminum runabout are not the same as those of a cabin cruiser.

2.0 CLASSIFICATIONS

In this section, the various boat classifications to be used in specifying environmental factors boundary conditions are established. The various boat subsystems are defined, as are the various relevant environmental elements and their gross level effects.

2.1 Classification of Recreational Boats

Attention is restricted to monohull recreational boats under 50 ft (15.2 m) in length with propeller or water jet propulsion systems. The specific characteristics initially used to define the various categories are the following:

- Propulsion System Type
- Length
- Weight
- Hull Design Type
- Hull Material
- Boat Type

Propulsion System Type - A boat to which these environmental specifications apply is typed according to its power system, such as:

- Inboard
- Outboard
- Stern Drive (I/O)
- Water Jet

Length - The length (L) of a boat can be classed according to existing USCG practices:

- $L < 16$ ft (4.9 m)
- 16 ft (4.9 m) $<$ 26 ft (7.9 m)
- $L \geq 26$ ft (7.9 m)

Weight - Although the weight (W) of a boat is obviously not independent of its length, there appears to be enough variation to warrant a breakdown of this parameter. One such suggested breakdown is:

- $W \le 400$ lb (181.4 kg)
- 400 lb (181.4 kg) $< W \le$ 1500 lb (680.4 kg)
- 1500 lb (680.4 kg) $< W \le$ 3000 lb (1360.8 kg)
- $W > 3000$ lb (1360.8 kg)

Hull Design Type - The hull design of a boat can be classified according to the following familiar partial list:

- Vee
- Cathedral
- Flat Bottom

Hull Material - The types of vessels under consideration have hulls primarily constructed of:

- Aluminum
- Wood
- Fiber-reinforced Plastic

Boat Type - The designed purpose of the craft can be classed as:

- Runabout
- Cruiser
- Open

Within each of the six boat characteristics above, there are several divisions. For example, only the three most common materials are shown under the hull material category. Other materials used in boat hull construction include steel, ABS, and various combinations of materials. Further subdivisioning to include the various combinations could become an almost endless task and would defeat the purpose of categorizing.

Tables III-1 through III-4 have been prepared as samples to illustrate how the length, weight, hull design, and hull material characteristics could be handled for each of the four propulsion system types. Each table would contain a maximum of 324 cells of information. For the four propulsion systems, therefore, there are 1296 cells. The majority of these cells will contain no data representative of any recreational boat; therefore, a finalized version of these tables could be greatly reduced. Also, results from such a compilation could warrant a revision in the category breakdown such as weight, length, and materials. If a process, as has been outlined herein, were carried out, a boat population density by category would be the output. Such a categorized boat population density, as is pictorially shown in Figure III-1, would have one primary purpose. It would indicate potential areas for concentrating further efforts in determining subsystem environmental effects on a cost effective basis. Wyle recognizes that such an undertaking requires the cooperative efforts of boat manufacturers and owners in a survey that could render only marginal results. An alternative approach would be to subcontract the data gathering task to BUC International Corporation of Ft. Lauderdale, Florida, if the cost were not prohibitive for the expected returns.

In lieu of the above described process for deriving boat population densities based upon selected categorization, Wyle derived Tables III-5 and III-6 from the Nationwide Boating Survey (Reference 1) data. This was an expedient means of obtaining some rough estimates of boat population densities based on imprecise categorization. Although some of these results could possibly be in error, Table III-5 provides a relative density of boats within the overall boat population. There are several power-type/length categories that contain high densities of boats with the single engine outboard boats under 16 ft (4.9 m) being the most common. Therefore, independent of Tables III-1 through III-4 and their subsequent population densities, Tables III-5 and III-6 could provide a starting point for concentrating future efforts.

2.2 Classification of Recreational Boat Subsystems

A boat shall be considered to consist of the following subsystems:

- Fuel Subsystem - This is the entire assembly of the fuel fill, vent, storage and distribution components, including pumps, valves, strainers, and filters.

TABLE III-1. CATEGORIES FOR RECREATIONAL BOATS WITH OUTBOARD PROPULSION SYSTEMS

CLASS/ LENGTH	WEIGHT (LB)**	VEE									CATHEDRAL									FLAT								
		RUNABOUT			OPEN			CRUISER			RUNABOUT			OPEN			CRUISER			RUNABOUT			OPEN			CRUISER		
		FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD
(<16 ft) *	≤ 400																											
	401 - 1500																											
	1501 - 3000																											
	> 3000																											
(16 ft < 26 ft)	≤ 400																											
	401 - 1500																											
	1501 - 3000																											
	> 3000																											
(≥ 26 ft)	≤ 400																											
	401 - 1500																											
	1501 - 3000																											
	> 3000																											

EXAMPLE EXHIBIT

LEGEND:

FRP - Fiber-reinforced Plastic

AL - Aluminum

WD - Wood

* To convert feet to meters multiply by 0.3048

** To convert pounds to kilograms multiply by 0.4536

TABLE III-2. CATEGORIES FOR RECREATIONAL BOATS WITH INBOARD PROPULSION SYSTEMS

CLASS/ LENGTH	WEIGHT (LB) **	VEE									CATHEDRAL									FLAT								
		RUNABOUT			OPEN			CRUISER			RUNABOUT			OPEN			CRUISER			RUNABOUT			OPEN			CRUISER		
		FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD
(< 16 ft) *	≤ 400																											
	401 - 1500																											
	1501 - 3000																											
	> 3000																											
(16 ft < 26 ft)	≤ 400																											
	401 - 1500																											
	1501 - 3000																											
	> 3000																											
(≥ 26 ft)	≤ 400																											
	401 - 1500																											
	1501 - 3000																											
	> 3000																											

EXAMPLE EXHIBIT

LEGEND:

FRP - Fiber-reinforced Plastic

AL - Aluminum

WD - Wood

* To convert feet to meters multiply by 0.3048

** To convert pounds to kilograms multiply by 0.4536

292-531 (32)

(32)

TABLE III-3. CATEGORIES FOR RECREATIONAL BOATS WITH STERN DRIVE PROPULSION SYSTEMS

CLASS/ LENGTH	WEIGHT (LB)**	VEE									CATHEDRAL									FLAT								
		RUNABOUT			OPEN			CRUISER			RUNABOUT			OPEN			CRUISER			RUNABOUT			OPEN			CRUISER		
		FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD
	≤400																											
	401 - 1500																											
(< 16 ft)*	1501 - 3000																											
	> 3000																											
	≤400																											
	401 - 1500																											
(16 ft < 26 ft)	1501 - 3000																											
	> 3000																											
	≤400																											
	401 - 1500																											
(≥26 ft)	1501 - 3000																											
	> 3000																											

EXAMPLE EXHIBIT

LEGEND:

FRP - Fiber-reinforced Plastic

AL - Aluminum

WD - Wood

* To convert feet to meters multiply by 0.3048

** To convert pounds to kilograms multiply by 0.4536

TABLE III-4. CATEGORIES FOR RECREATIONAL BOATS WITH WATER JET PROPULSION SYSTEMS

CLASS/ LENGTH	WEIGHT (LB) **	VEE									CATHEDRAL									FLAT								
		RUNABOUT			OPEN			CRUISER			RUNABOUT			OPEN			CRUISER			RUNABOUT			OPEN			CRUISER		
		FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD	FRP	AL	WD
(< 16 ft) *	≤ 400																											
	401 - 1500																											
	1501 - 3000																											
	> 3000																											
(16 ft < 26 ft)	≤ 400																											
	401 - 1500																											
	1501 - 3000																											
	> 3000																											
(≥ 26 ft)	≤ 400																											
	401 - 1500																											
	1501 - 3000																											
	> 3000																											

EXAMPLE EXHIBIT

LEGEND:

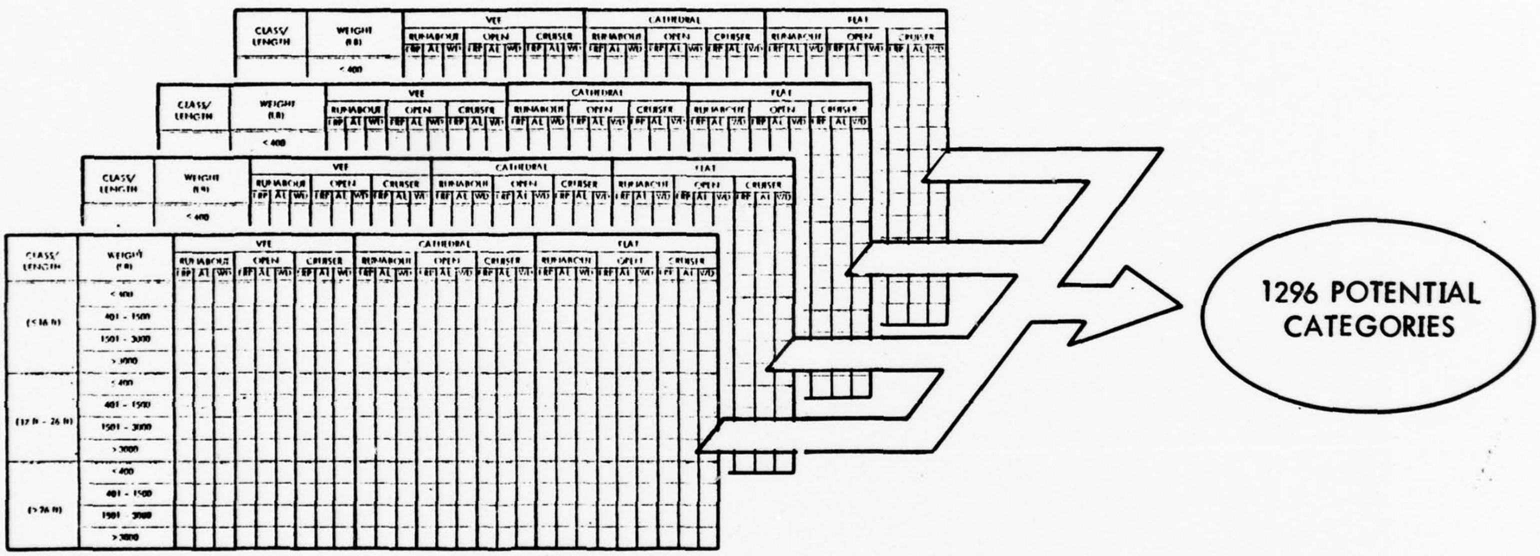
FRP - Fiber-reinforced Plastic

AL - Aluminum

WD - Wood

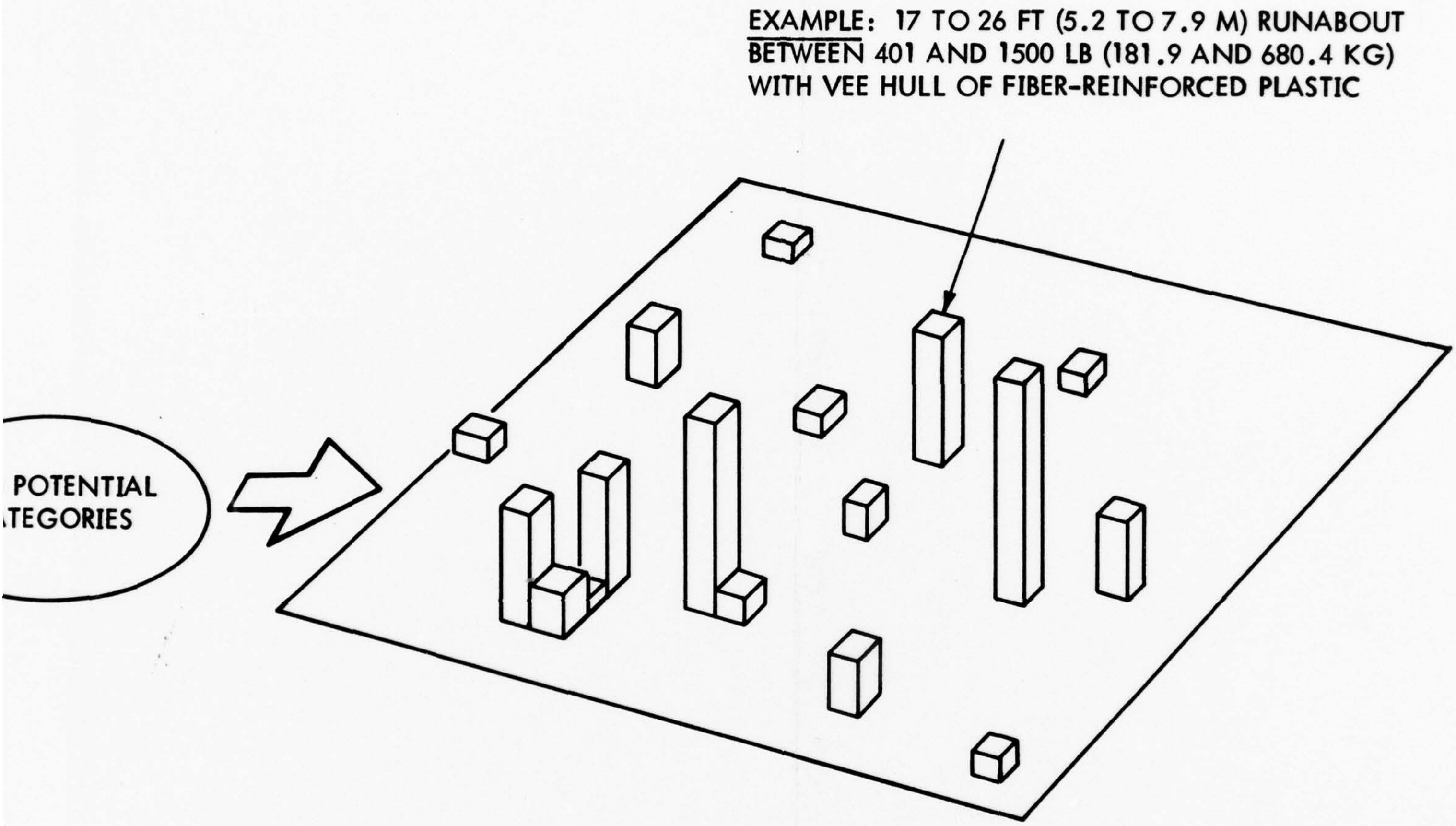
* To convert feet to meters multiply by 0.3048

** To convert pounds to kilograms multiply by 0.4536



TABLES III-1 THROUGH III-4

1



CATEGORIZED BOAT POPULATION DENSITY

2

FIGURE III-1. BOAT POPULATION DENSITY BY CATEGORY

292-531 PASTER #1 FACE ONLY
FACE PAGE 34
1

35 36X

TABLE III-5. POPULATION DENSITY OF BOATS BY TYPE/LENGTH CATEGORIZATION PROVIDING EIGHTY CELLS OF INFORMATION

(DATA DERIVED FROM NATIONWIDE BOATING SURVEY (REFERENCE 1))

		LENGTH CATEGORIES			
TYPE OF CRAFT		$L < 16$ *	$16 \leq L < 26$	$L \geq 26$	Unknown
1.	Canoes	92	119	0	21
2.	Houseboats	2	8	11	1
3.	Inboard, gas, single engine	37	111	18	2
4.	Inboard, gas, twin engine	2	10	17	1
5.	Inboard, diesel, single engine	0	3	20	0
6.	Inboard, diesel, twin engine	78	128	2	6
7.	Inboard/Outdrive, single engine	1	13	3	0
8.	Inboard/Outdrive, twin engine	8	0	0	0
9.	Inflatable	54	4	0	4
10.	Johnboat	7	3	1	4
11.	Kayak	7	3	0	0
12.	Outboard, single engine	1708	380	14	93
13.	Outboard, twin engine	67	21	0	4
14.	Rowboat	377	22	0	34
15.	Sailboat, gas auxiliary	4	25	5	0
16.	Sailboat, diesel auxiliary	0	0	8	0
17.	Sailboat, no auxiliary	111	19	5	8
18.	Other powerboat	12	9	2	3
19.	Other	131	40	6	14
20.	Don't know	17	4	0	7

* L = Length (Feet) (To convert feet to meters multiply by 0.3048)

5/5

292-531 35

37

TABLE III-6. NUMBER OF BOATS BY TYPE AND AGE IN BOAT POPULATION — 440 CELLS OF INFORMATION

(DATA DERIVED FROM NATIONWIDE BOATING SURVEY (REFERENCE 1))

	AGE (YEARS)																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Don't Know
1. Canoes	97	41	31	36	18	26	7	7	10	3	0	12	0	3	3	8	0	0	0	2	12	0
2. Houseboats	0	15	4	3	2	3	1	1	0	1	1	0	1	0	1	0	0	0	0	2	0	0
3. Inboard, gas, single engine	1	13	7	13	15	14	13	9	8	10	13	2	7	3	4	9	2	0	1	3	16	0
4. Inboard, gas, twin engine	10	3	4	2	1	1	0	6	0	1	0	2	0	0	2	0	0	2	1	2	2	0
5. Inboard, diesel, single engine	1	1	1	1	1	0	0	2	0	0	0	2	0	0	1	2	0	0	0	1	0	0
6. Inboard, diesel, twin engine	0	0	1	0	0	2	1	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0
7. Inboard/Outboard, single engine	2	25	17	29	21	31	19	23	8	4	8	5	6	1	1	2	0	0	0	2	1	0
8. Inboard/Outboard, twin engine	12	3	2	1	2	2	1	1	0	2	0	1	0	0	1	0	0	0	0	0	0	0
9. Inflatable	1	2	2	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
10. Johnboat	1	9	5	7	5	12	6	4	2	1	0	0	0	0	4	0	0	0	0	1	1	0
11. Kayak	4	1	1	2	1	0	0	0	0	1	0	2	0	0	0	0	0	0	0	1	0	0
12. Outboard, single engine	1	186	186	244	196	233	149	114	132	53	217	32	81	24	39	74	32	12	14	13	54	0
13. Outboard, twin engine	22	8	10	4	6	8	5	3	2	1	11	2	2	1	1	7	0	0	0	1	6	0
14. Rowboat	2	30	39	47	32	44	22	25	28	3	45	2	18	2	6	0	0	29	0	3	19	0
15. Sailboat, gas auxiliary	45	4	4	7	1	4	4	2	1	0	0	0	1	2	1	0	0	0	0	2	0	0
16. Sailboat, diesel auxiliary	5	0	1	0	0	2	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
17. Sailboat, no auxiliary	1	20	26	21	9	15	9	6	0	7	0	8	3	1	1	0	0	0	0	3	10	0
18. Other powerboat	4	1	4	5	2	6	3	1	0	1	0	0	0	2	1	0	0	0	0	0	1	0
19. Other	1	21	16	24	16	21	13	11	10	2	11	4	4	2	3	8	0	0	0	3	11	0
20. Don't know	13	1	2	4	3	1	4	0	0	1	0	0	0	0	1	0	3	0	0	0	1	6

292-531 36

- Electrical Subsystem - This is the entire assembly of all electrical components, wiring and electrically operated devices.
- Ventilation Subsystem - The ventilation subsystem consists of all hardware associated with engine compartment ventilation - blowers, vents, and cowls.
- Instrumentation Subsystem - The instrumentation subsystem is the collection of devices, electrical or mechanical, which provide measurements of the boat's operational parameters which are needed by the operator, e.g., fuel level, engine temperature, and vapor detectors.
- Propulsion Subsystem - The propulsion subsystem consists of the engine, drive train and propeller.
- Hull Subsystem - The hull subsystem consists of the basic boat assembly less all of the items contained in the other five subsystems.

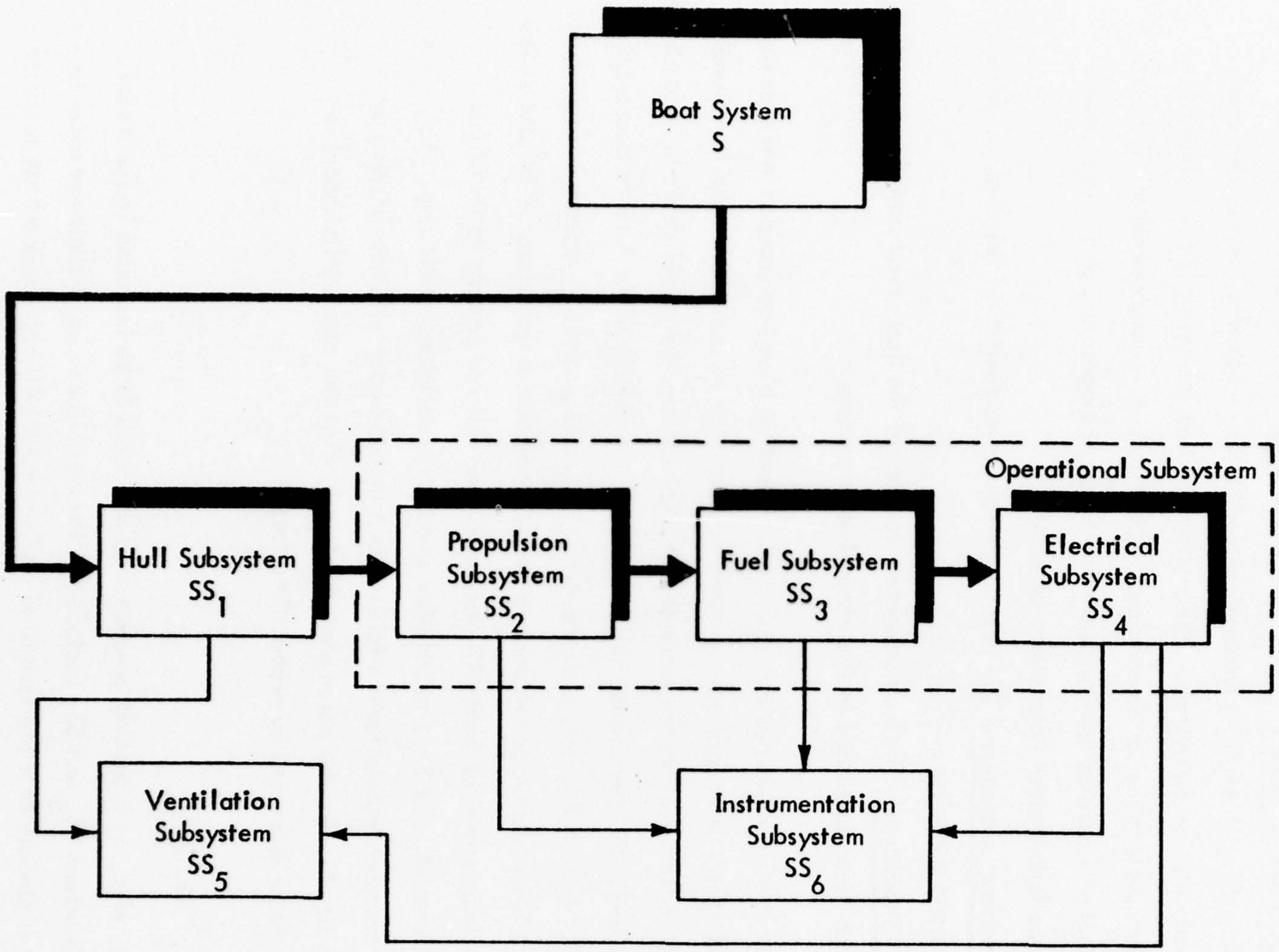
The boat as a system can be viewed as a complex of interacting elements grouped and organized into functional subsystems. Any boat can be modeled according to some particular functional criteria. If the only criteria of interest were operational ability, the model could be represented as shown in Figure III-2. By operational ability is meant the ability of the boat to operate/perform as designed. In this diagram, subsystems SS_1, SS_2, SS_3, and SS_4 represent single point failures in that each is necessary for the boat to operate/perform as designed. A failure or loss of any one of these four means the boat will not operate or will not operate to its fullest capability. Subsystems SS_5 and SS_6, ventilation and instrumentation, while important, their loss does not necessarily constitute a failure such that the boat will not function or operate. If operability * were the parameter of interest, then the operability model for the boat system could be expressed by probabilities as:

$$O_S = \sum_{i=1}^{4} O_{SS_i} .$$

However, safety is, also, an important parameter which needs to be included in the model. Figure III-3 has subsystems SS_5 and SS_6 included in the model because of their necessity to safe operation. It is obvious that the failure of an instrument will not cause a boat to cease

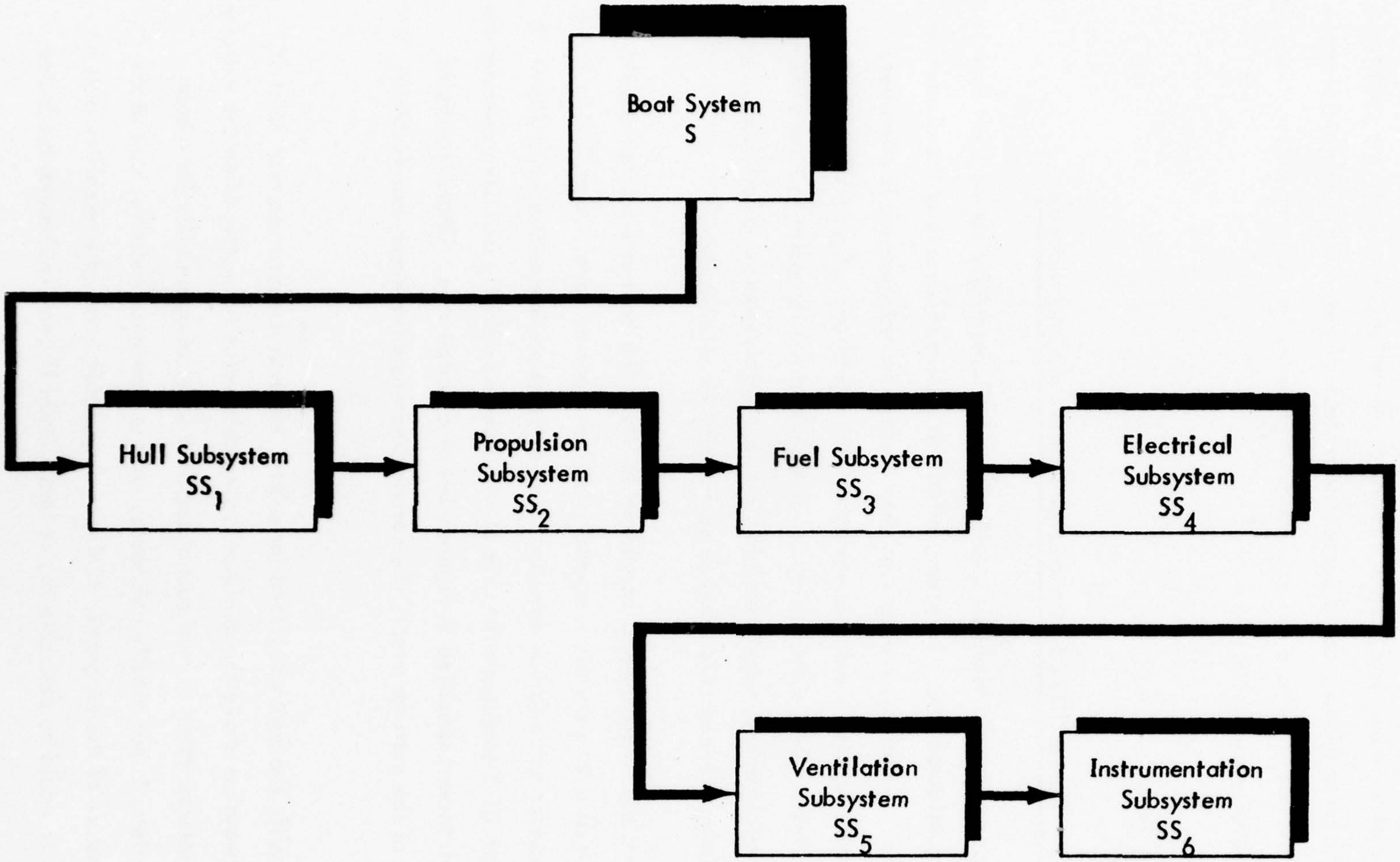
---

* Operability as used in this example is derived from reliability engineering theory and practices. Mathematically, operability can be defined as the probability of no failure of malfunction occurring during a given time frame when the unit is called upon to perform.



Equation for system operability: $O_S = O_{SS_1} \cdot O_{SS_2} \cdot O_{SS_3} \cdot O_{SS_4}$

FIGURE III-2. BOAT SYSTEM MODEL FOR OPERATIONAL ABILITY (OPERABILITY)



Equation for system safe operability: $O_S = O_{SS_1} \cdot O_{SS_2} \cdot O_{SS_3} \cdot O_{SS_4} \cdot O_{SS_5} \cdot O_{SS_6}$

FIGURE III-3. BOAT SYSTEM MODEL FOR SAFE OPERATIONAL ABILITY

operations, but faulty or erroneous signals could prevent an operator from taking safety precautions in the event of an impending hazard. Likewise, a malfunction within the ventilation subsystem, such as a blower failure, could permit the buildup of hazardous fumes and vapors that ultimately could result in a fire or an explosion. Therefore, for "safe operational ability," the operability model for a boat system is:

$$O_S = \sum_{i=1}^{6} O_{SS_i} .$$

2.3 Operability, Environmental Impact, and Maintenance

Boat subsystems must operate at a minimum specified level of operability during their useful lives in order to be considered safe. However, often this minimum level is at the discretion of the owner/operator. Therefore, a boat/subsystem lacking in maintenance is often very susceptible to premature failure in extreme environmental conditions. Figure III-4, Environment vs. Time, and Figure III-5, Operability vs. Time, illustrate the point that an extreme environmental incident (event) is sometimes sufficient to severely damage a boat/subsystem so that it is below a minimum acceptable level of operability for safe boating.

Figure III-4 represents the environmental conditions to which the boat or subsystem should be qualified. It consists of a long duration (several years) at a normal level (Point "A" to Point "B") followed by a sudden spike (a few minutes) to an extreme environmental level (Point "B" to Point "C"). Figure III-5 represents the rate at which the operability deteriorates under the influence of the environment specified in Figure III-4 at a modest rate. Under the added environmental stress of the extreme event, the deterioration rate increases sharply (Point "B" to Point "C").

Simply stated, to qualify the boat subsystems for safety, we must demonstrate that Point "C", Figure III-5, will always be above the minimum acceptable value no matter when the extreme event occurs. The determination of minimum acceptable level of operability for a boat component, or subsystem, is not readily definable. In the aerospace industry, due to the critical and costly nature of the programs, minimum acceptable level of operability must be known. In boating, it would be desirable to, at least, know if peak environmental factors

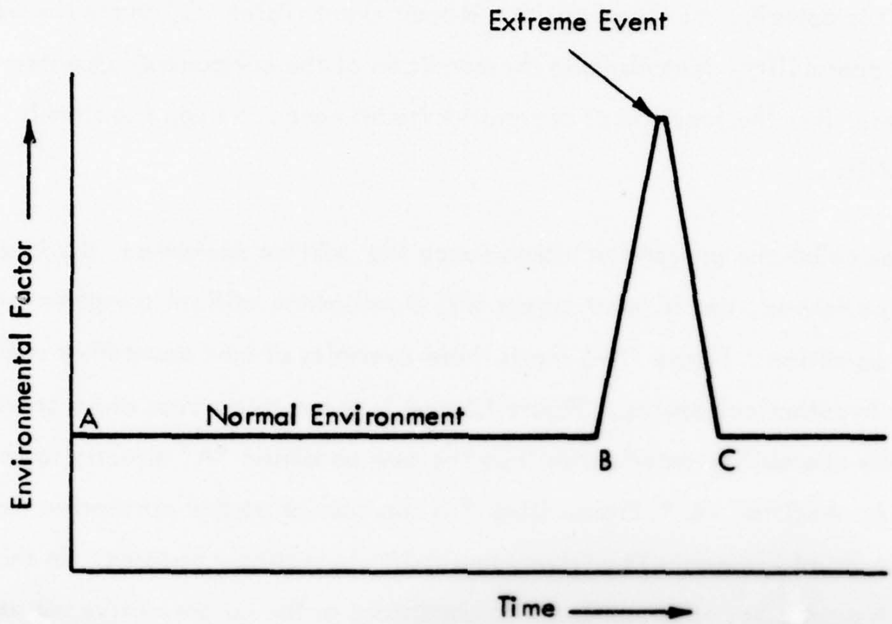


FIGURE III-4. ENVIRONMENT VS. TIME

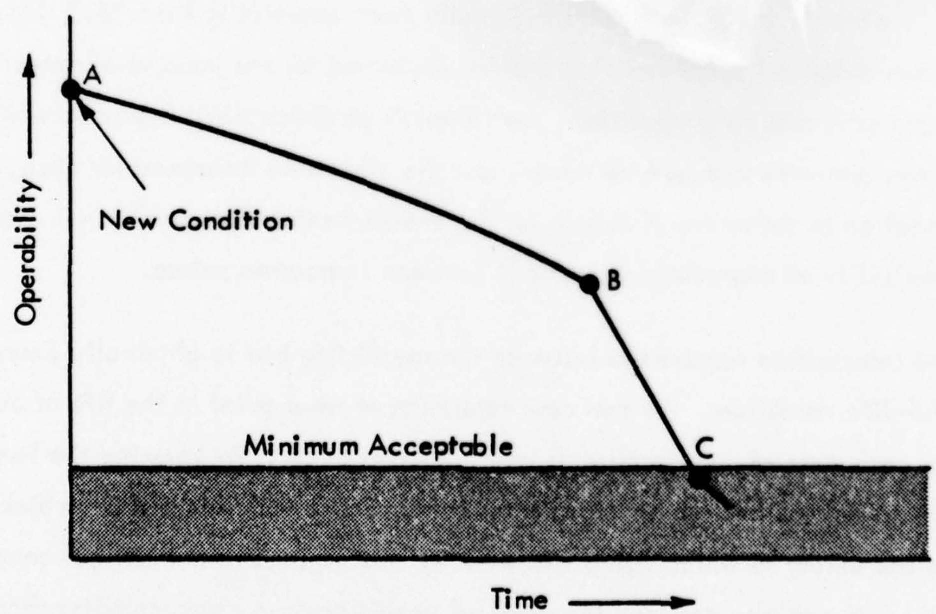


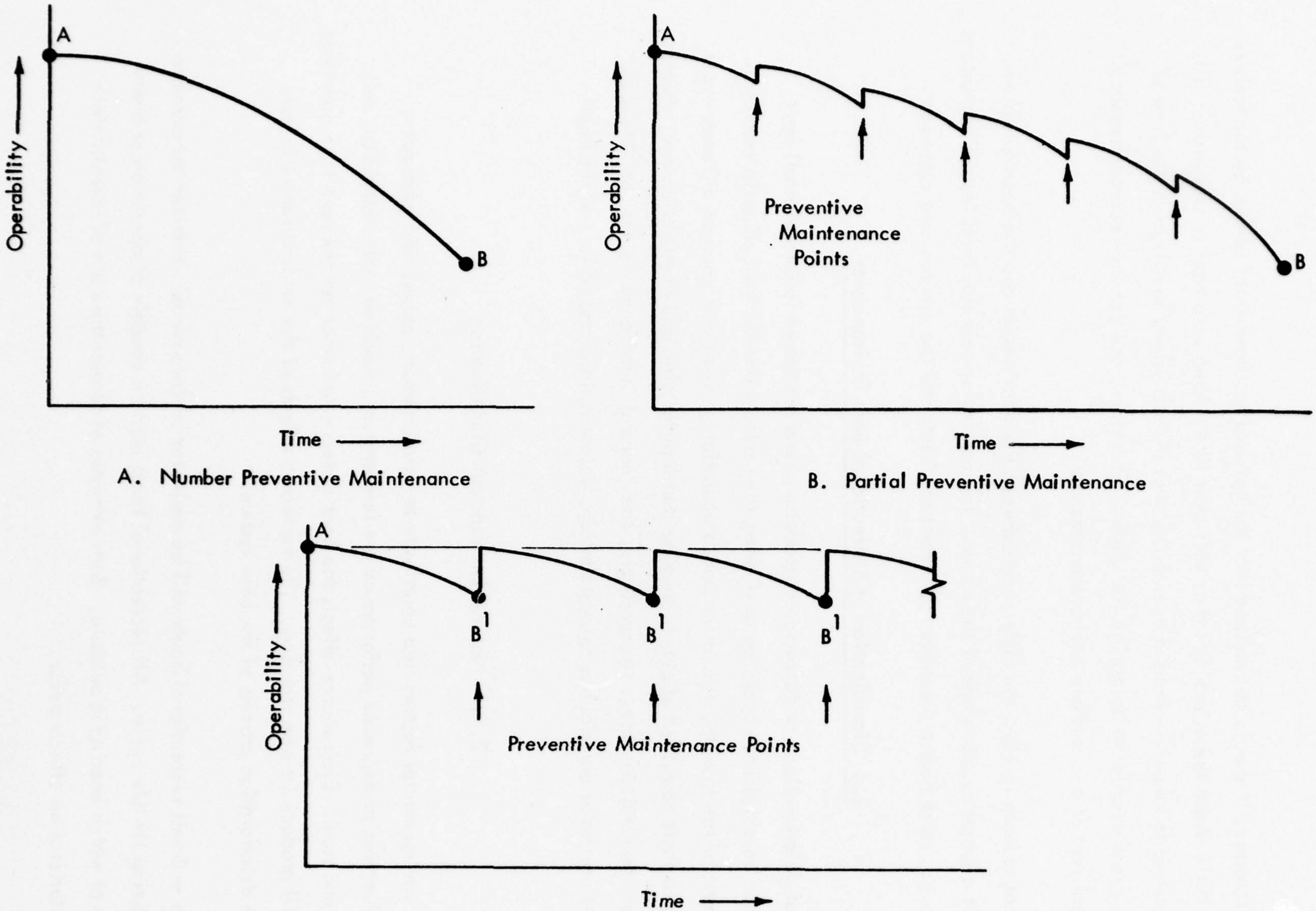
FIGURE III-5. OPERABILITY VS. TIME

could be planned for such that the subsystem or component would have a high probability of survival in the event of their occurrences.

From Figure III-5, it is apparent that survival from a peak event (Point "C" above the minimum acceptable level of operability) depends upon the condition of the component/subsystem at the time of the event. It is the function of preventive maintenance to keep the item in a high state of operability.

The next step is to establish the preventive maintenance that will be performed, the intervals at which it will be performed, and to what extent will it return the critical components/subsystems to a "new" condition. Figure III-6 shows three examples of how preventive maintenance effects the life of a hypothetical device. Figure III-6-A is the extreme case of no preventive maintenance, and the operability deteriorates from the new condition "A" directly to the end-of-qualified-life condition "B." Figure III-6-B is the case of partial preventive maintenance (e.g., cleaning and visual inspection) by which operability is partially restored. In this case, the device reaches the same end-of-qualified-life conditions as the no preventive maintenance case. It just takes more time to get to that condition. Figure III-6-C is the other extreme case, which is total preventive maintenance (e.g., overhaul, cleaning, and functional checking) by which operability is totally restored. In this case, the device does not substantially deteriorate beyond "B^1", which is a condition of significantly more operability than "B." Next, we must define the surveillance inspections that will be performed for the purpose of detecting the onset of an end-of-useful-life condition, the intervals at which these inspections will be performed, the measurements that will be taken, and the allowable tolerance for each. This information is required to determine if margin on the end-of-useful-life condition is required to negate the possibility of degradation beyond it between inspection points.

We now have the information required to estimate the useful life and to physically describe the end-of-useful-life condition. We can now determine at what point in the life of our device its worse-case state of deterioration is most likely to occur. By knowing the length of time it will be in service and the environmental conditions to which it will be subjected, we can estimate the extent to which aging and wear will take place in the critical components/subsystems. We can also describe the physical conditions and characteristics that these aged components/subsystems will exhibit.



A. Number Preventive Maintenance

B. Partial Preventive Maintenance

C. Total Preventive Maintenance

FIGURE III-6. EFFECT OF PREVENTIVE MAINTENANCE

From this discussion, it should be realized that the extreme environmental factors by themselves tell us very little about the effect that they will most likely have on a boat or subsystem. It is equally important to know the state of operability that the subsystem/boat is in at the time of the extreme event in order to determine the effect. Therefore, maintenance approaches should be an integral part of a subsystems environment manual.

Is is important to keep in mind the difference between the boat system and the boating system. The former is a subset or subsystem of the latter. The boating system also includes the operations subsystem (e.g., some human elements that affect the boat) and the environment subsystem.

2.4 Classification of Recreational Boat Environments

The causes of deterioration, performance degradation, and premature failure of small boat subsystems can be classified according to whether they arise primarily from climatic conditions and/or because of the stressing due to the boat's operations. Each will produce different types of stresses with their combined effects increasing the deterioration and degradation and, thereby, increase subsystems failure rates. Accordingly, the "natural" environments and the "induced" environments are major contributors to degradation, deterioration, and failure of the boat subsystems.

2.4.1 Natural Environment Classification

The natural environmental factors that contribute to deterioration, aging, and subsequent failure/malfunction or degraded performance are temperature, sunshine, rain, humidity, salt spray, dust and sand. Each source affects the boat system whether or not the boat is in operation and each will produce its own stressing. The combined effects of the environmental factors increase the deterioration process of the boat system.

Temperature — Small recreational boats will be subjected to considerable ambient temperature variations during its life cycle. All recreational boats must be capable of operation at every temperature at which boating is possible. Both extremes of temperature are of interest since different deterioration effects occur.

Expansion and contraction caused by wide temperature variations cause deterioration of organic and plastic materials. Discoloration, cracking, bulging, checking and crazing of plastics, synthetic rubber and plywood occur after prolonged exposure to elevated temperatures. Also, exposed lubricated surfaces may be left dry because of the evaporation of the lubricant. Differential expansion of dissimilar metals can cause loosening of connections and mounting bolts. Low temperature effects are mainly confined to increasing the viscosities of the lubricants.

Sunlight — Prolonged exposure to sunlight will cause deterioration of plastics, paints, fabrics and natural rubber by means of photochemical mechanisms.

Rain — A rain environment will introduce excessive moisture into the vessel itself and promote oxidation of metals, the growth of fungi, and possible malfunction of some of the boat subsystems if not adequately protected.

Humidity — A highly humid atmosphere can induce corrosion and will produce swelling of such water absorbing materials as wood. Higher ambient temperatures will speed these processes and will foster the growth of fungi in the humid atmosphere.

Salt Spray — The dominant effect of salt spray is the corrosion of exposed metals, whether by corrosion of one metal alone or by electrolytic action between two dissimilar metals. Salt deposits may build up and may clog or bind moving parts.

Sand and Dust — Transportation of boats provides exposure to a dust and/or sand environment. Wind driven sand and dust can cause erosion and the lodging of contaminants in between moving parts and surfaces causing abrasive scoring and/or excessive wear leading ultimately to component/parts failure and/or premature replacement. Accumulated dust and sand can cause clogging of filters and blockage of movement.

2.4.2 Induced Environment Classifications

Induced environments arise from the actual motion of the boat during operation or while being transported. These environmental factors are acceleration, vibration, shock, noise and temperature. In addition to these standard environmental factors, fuel spills and leaks

constitute further sources of materials and boat subsystems deterioration and degradation. Also, a fuel vapor atmosphere is a critical explosive hazard. Therefore, fuel will be considered an induced environmental factor.

Acceleration — Whenever the motion of the boat deviates from constant speed in a straight line each of its components will be subjected to an additional force by virtue of the acceleration to which it is subjected. An example of this is the horizontal force experienced by any component when the vessel is executing a turn. These forces can stress subsystem mounting brackets, slosh fuel within tanks (unless baffled), and, in general, act adversely on objects and passengers.

Vibration — Vibrations are induced by normal boating operations. The vibrations may be random, periodic or transient in nature, depending upon the type of excitation encountered. The amplitudes of this type of motion will generally be relatively small. Vibration of the subsystem components can induce excessive wear and fatigue in metal parts and instruments resulting in increased failure rates of components and parts. Vibrations are also induced by the operation of towing a boat on a trailer or by transportation by truck or flat car.

Shock — The relatively short-duration, high acceleration motions induced by such conditions as the boat slamming into waves during operation, the trailer hitting chuck holes or travelling over railroad crossings during transportation can cause severe damage to the structural integrity of the boat and its components.

Noise — The noise environment is of interest only during normal boating usage. Major sources of noise are the water-hull interaction and the engine generated noise. Also to be considered is the air (wind) noise. This environment is not considered to be detrimental to the structural integrity of the boat. However, excessive noise levels can cause hearing impairment in the operator and passengers, hamper communications, and impede reaction to correct or avoid hazardous conditions.

Fuel/Solvents — Volatile fuels, e.g., gasoline, can have two effects: deterioration of materials with which they come in contact, and creation of an explosive atmosphere due to leakage, evaporation, and inadequate ventilation.

Temperature — Induced internal (compartment) heat is generated by the engine. The retention of engine generated heat due to inadequately ventilated enclosures causes accelerated aging of the local hull subsystem materials and other items or components located or stored in this environment.

2.5 Boat/Subsystems Life Cycle

During its normal life, a boat, typically, cycles through the various activities of transportation, operation, and storage, each having effects on the boat and subsystems. Supportive activities are, therefore, essential to assure a level of operational status. These activities are inspection and preventive maintenance. In the event of a failure/malfunction of a subsystem or component, another supportive function of repair maintenance is required. Figure III-7, Life Cycle Activities of a Boat System, illustrates the flow for the activities beginning with a new boat and ending when it is scrapped. The optimization of such a flow is, of course, a function of a number of variables. A boat/subsystems can be optimized in accordance with one of several objectives. A system whose objective function is minimum life cycle cost will have a different set and sequence of cycling activities than will one whose objective function is maximum operational safety. The reduction of risk in the latter will have to be paid for by an increased cost or a reduction in other variables. In these two examples, the useful life will also be different. It should be apparent that the useful life of a particular boat class or category is a random variable due to the nature of the use to which the boats are put and the maintenance they receive. In this treatment of life cycles of boat systems, the intention is to illustrate the many owner decisions that must be made in maintaining a safe boat. It is the transportation/operation loop that a knowledge of subsystems environments can assist in minimizing failures that could precipitate in unsafe boat operations.

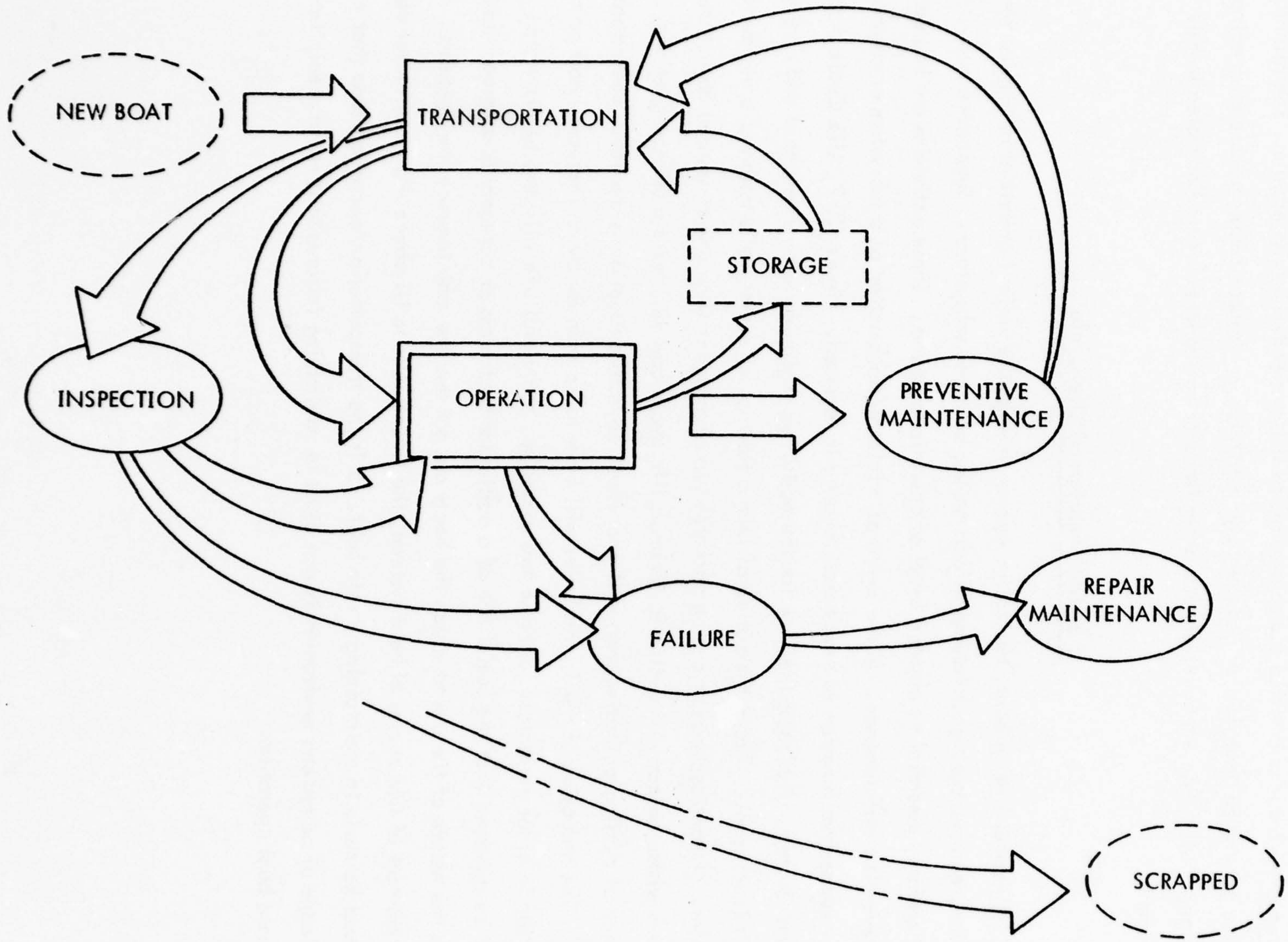


FIGURE III-7. LIFE CYCLE ACTIVITIES OF A BOAT SYSTEM

3.0 PRELIMINARY ENVIRONMENT SPECIFICATIONS

In this section, suggested formats for data presentation are given together with the data that is available. The formats were devised to minimize the work involved in expansion or reorganization of the data.

3.1 Natural Environment Specification

At present there exists more data for the specification of natural environments of recreational boats than induced environments, since climatic statistics have been compiled over a long period of time and are readily available.

Temperature, Precipitation, Sunshine and Humidity — Figures III-8 through III-13 depict available data on the following natural environments:

- Mean monthly average temperature
- Mean monthly minimum temperature
- Mean monthly maximum temperature
- Mean annual precipitation
- Monthly precipitation means and extremes
- Mean annual sunshine - Environmental data on monthly sunshine and relative humidity is also available

This data was compiled by the U.S. Geological Survey in 1965 from data provided by the Environmental Data Service, Environmental Services Administration for the period 1931-1960.

3.2 Induced Environment Specification

Any statement about the motion-induced environments which a boat will experience must also contain information as to the water conditions and the speed of the vessel in order for the statement to be meaningful. The water conditions can be defined in terms of average wave height, length and frequency of waves. Wind velocity might also be included in the definition of water conditions. The water conditions can be defined and categorized according to a water condition index as shown in Table III-7.

1a

RESCREEN & SQUARE HALFTONES

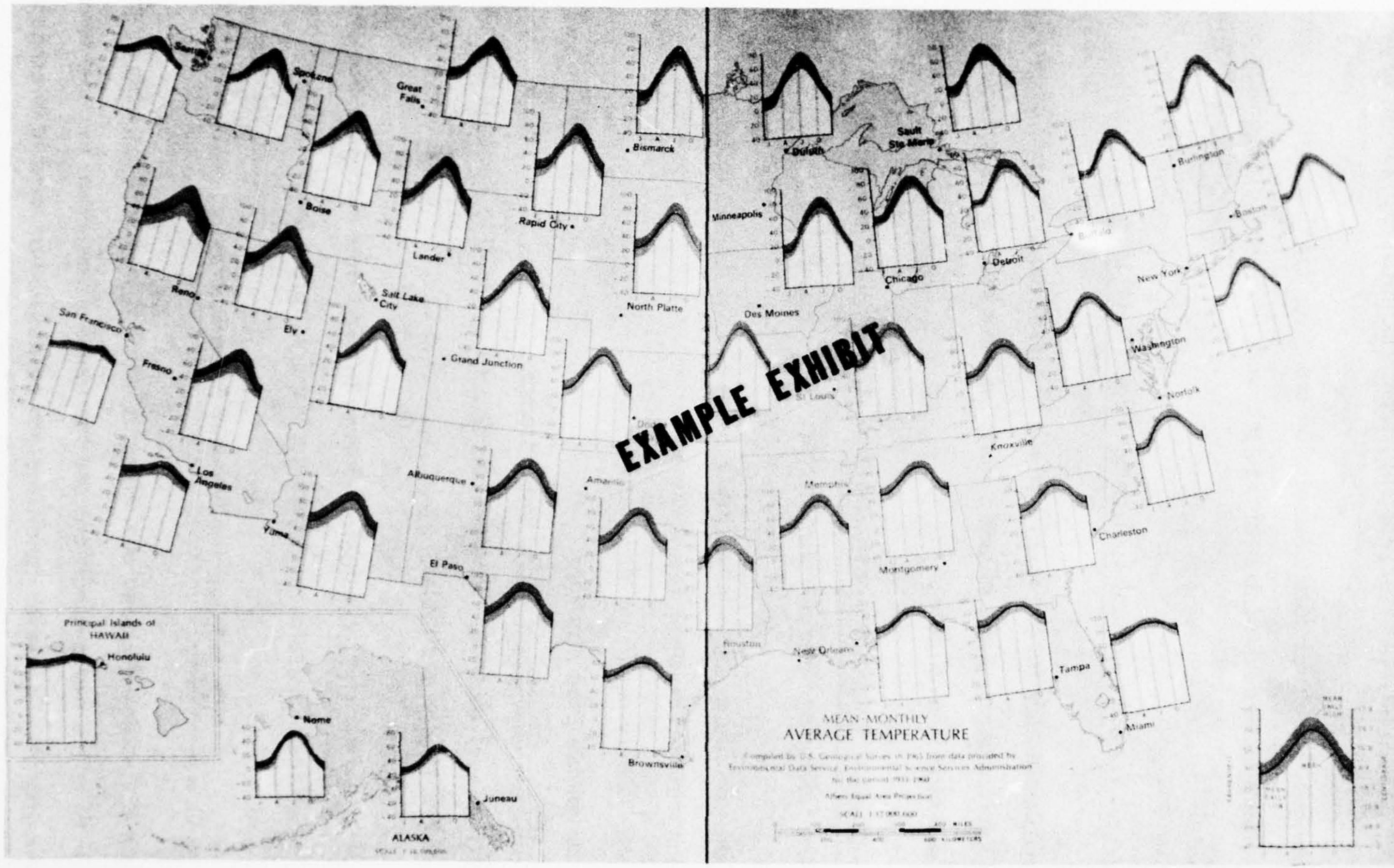


FIGURE III-8. MEAN MONTHLY AVERAGE TEMPERATURE

292-531

50

2a

RESCREEN & SQUARE HALFTONES

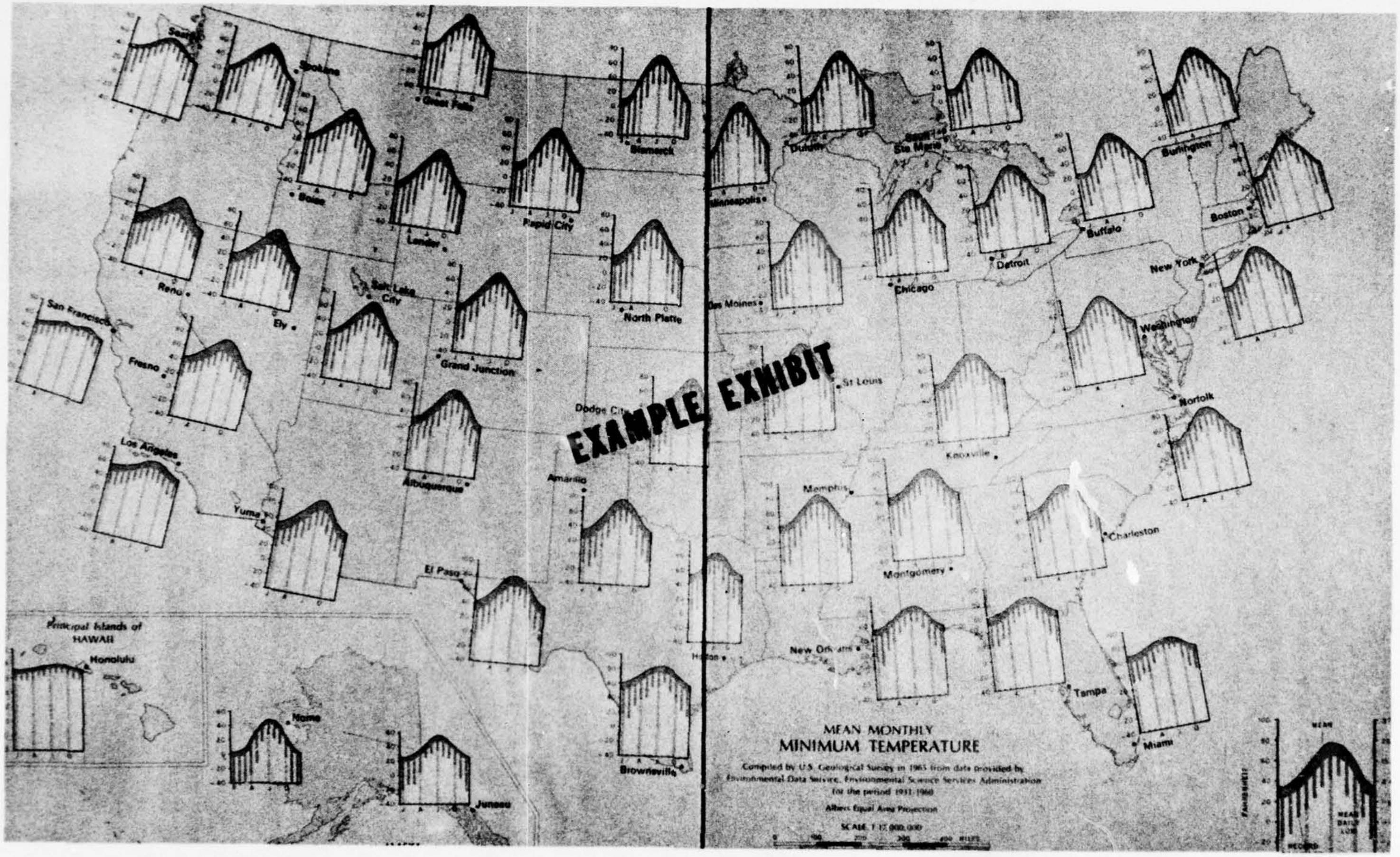


FIGURE III-9. MEAN MONTHLY MINIMUM TEMPERATURE

292-531 51

53

3a

RESCREEN & SQUARE HALFTONES

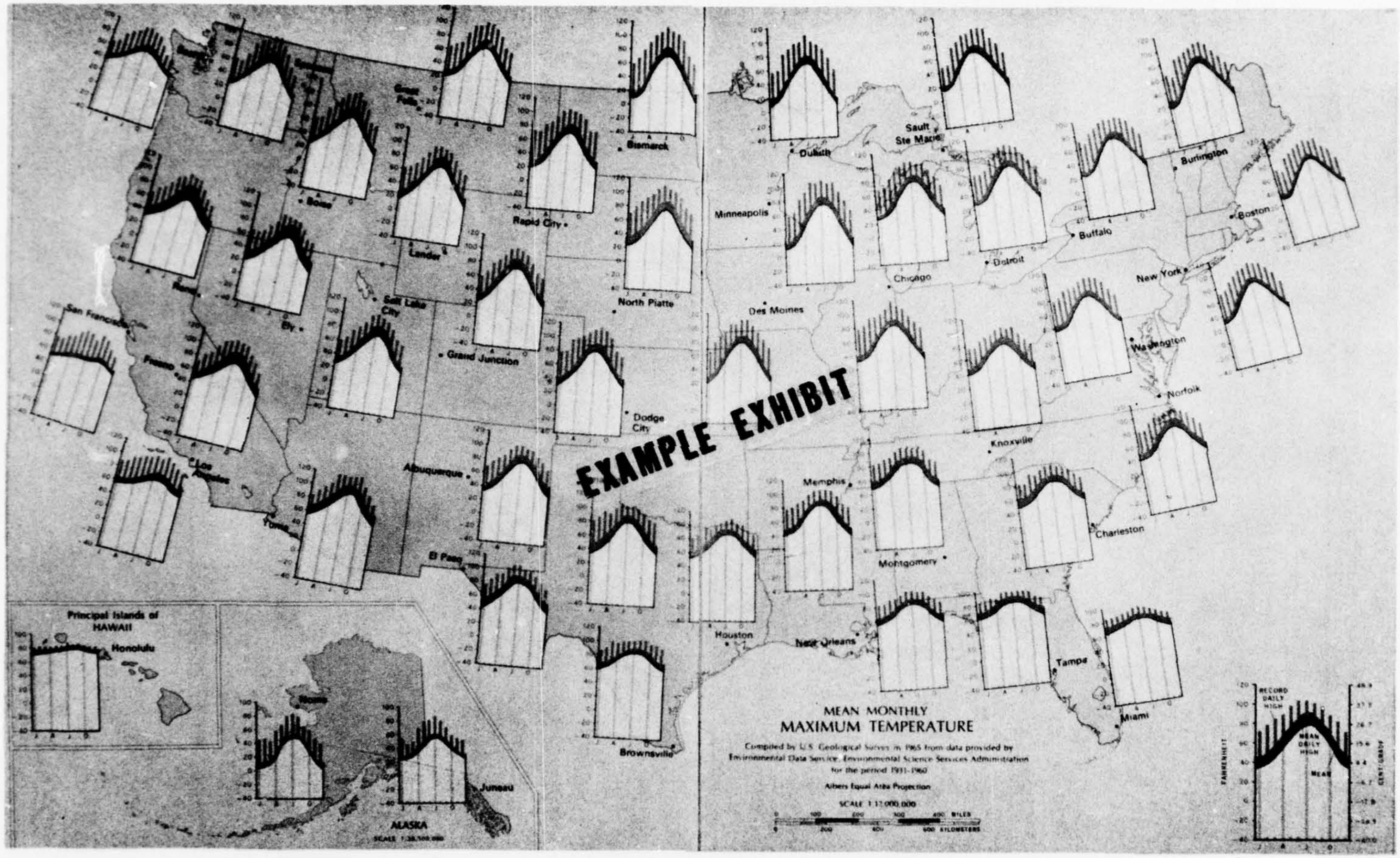


FIGURE III-10. MEAN MONTHLY MAXIMUM TEMPERATURE

292-531 52

54

4a

RESCREEN & SQUARE HALFTONES

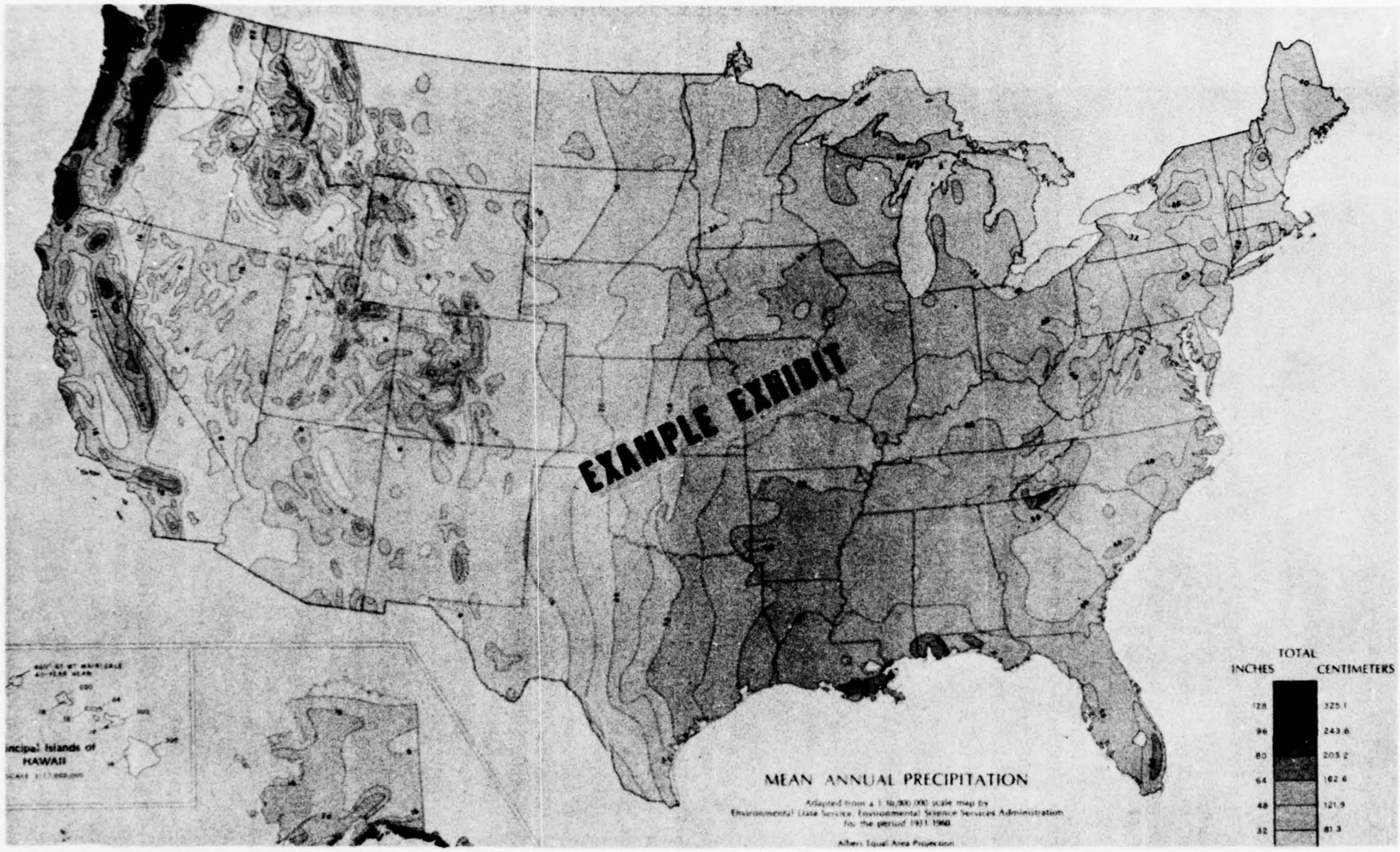


FIGURE III-11. MEAN ANNUAL PRECIPITATION

292-531 53

55

5a RESCREEN & SQUARE HALFTONES

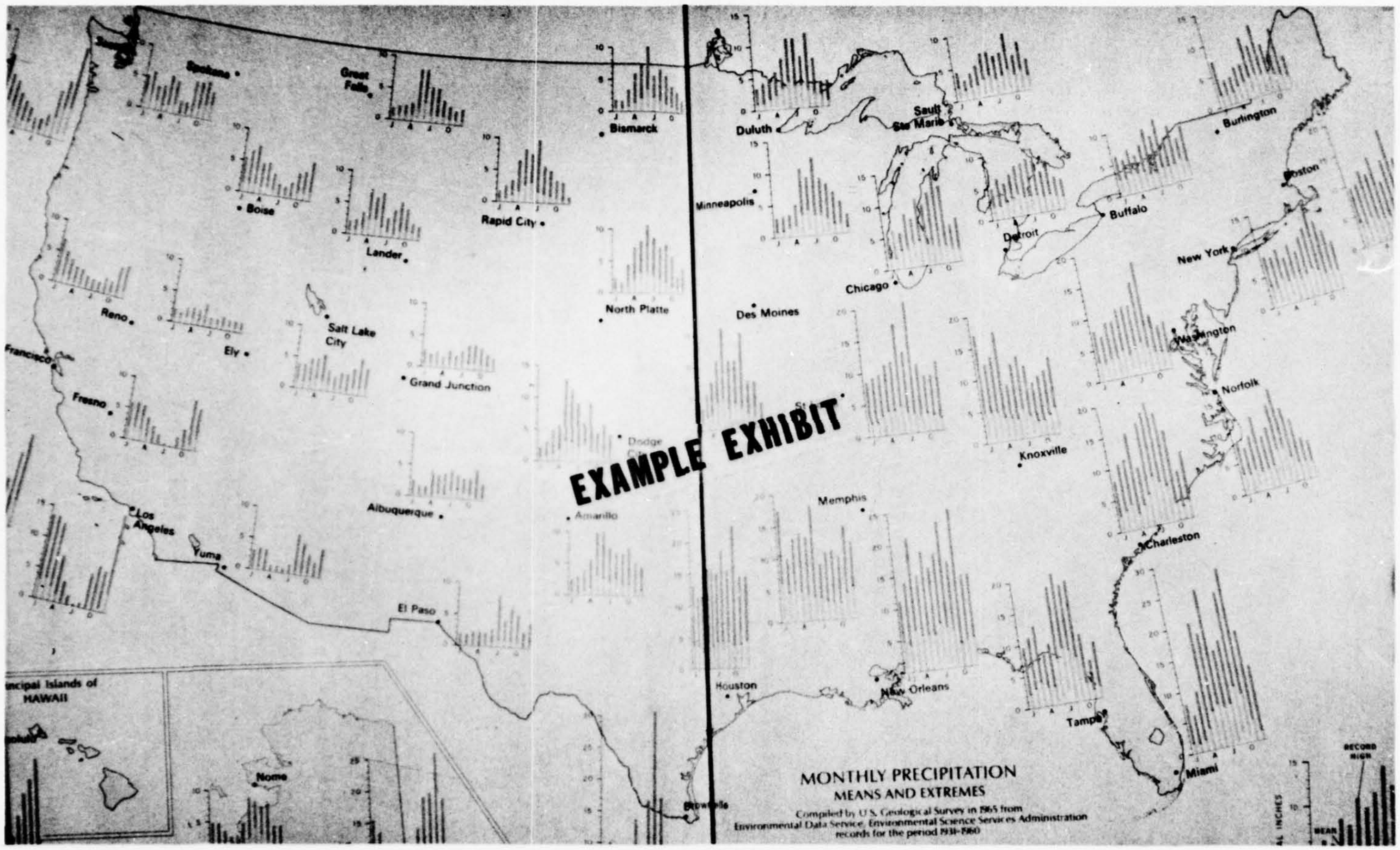


FIGURE III-12. MONTHLY PRECIPITATION MEANS AND EXTREMES

292-531 (54)

56

6a

RESCREEN & SQUARE HALFTONES

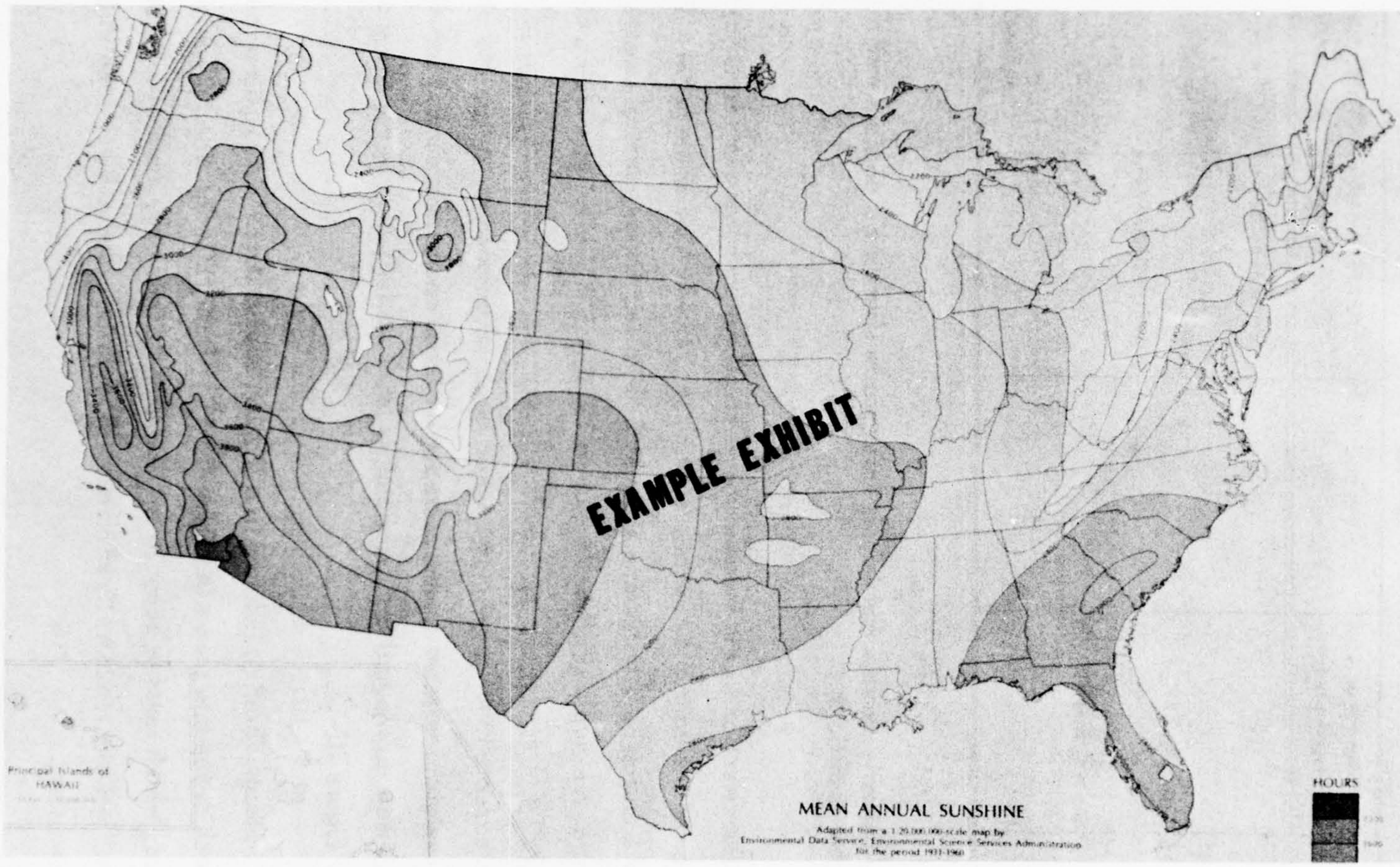


FIGURE III-13. MEAN ANNUAL SUNSHINE

292-531 55

57

TABLE III-7. WATER CONDITION INDEX

Water Condition Index Ranking	Average Wave Height	Average Wave Width	Frequency of Occurence	Water Condition Index
1	(H)	(W)	(F)	WCI = H • W • F
2				
3				
4				
.				
.				
.				
.				

EXAMPLE EXHIBIT

(Table III-7 is an example exhibit that is only intended to illustrate a possible method for categorizing water conditions.)

Acceleration — The direction of the induced forces on subsystem conponents is directed opposite to the acceleration of the boat and, hence, is parallel to the surface of the water. From measurements made during boat tests using the ABYC H-26 test course, lateral acceleration for the center of mass of relatively small boats - up to 18 ft (5.5 m) in length - indicate peak values of 1.5 to 2.0 g in emergency maneuvers with average values for maneuvers of 0.8 to 1.2 g. It can be expected that larger boats would have values decreasing from the above as boat length (and weight) increases (speed decreases). Level counts and distribution of acceleration levels at points on the hull are described by level analysis such as the one shown in the example exhibit, Figure III-14.

Vibration — The random vibration induced in a running boat is described by power spectral densities (PSD) such as the one shown in Figure III-15. These PSDs describe both engine induced vibrations, which seem to occur in the 100-200 Hz frequency band with levels to 2 or 3 g maximum, and any random vibration such as might be induced by running through choppy waters.

Vibration will occur in three directions: vertical, longitudinal and lateral, and will vary from location to location within any one boat. At present, it is not known whether the

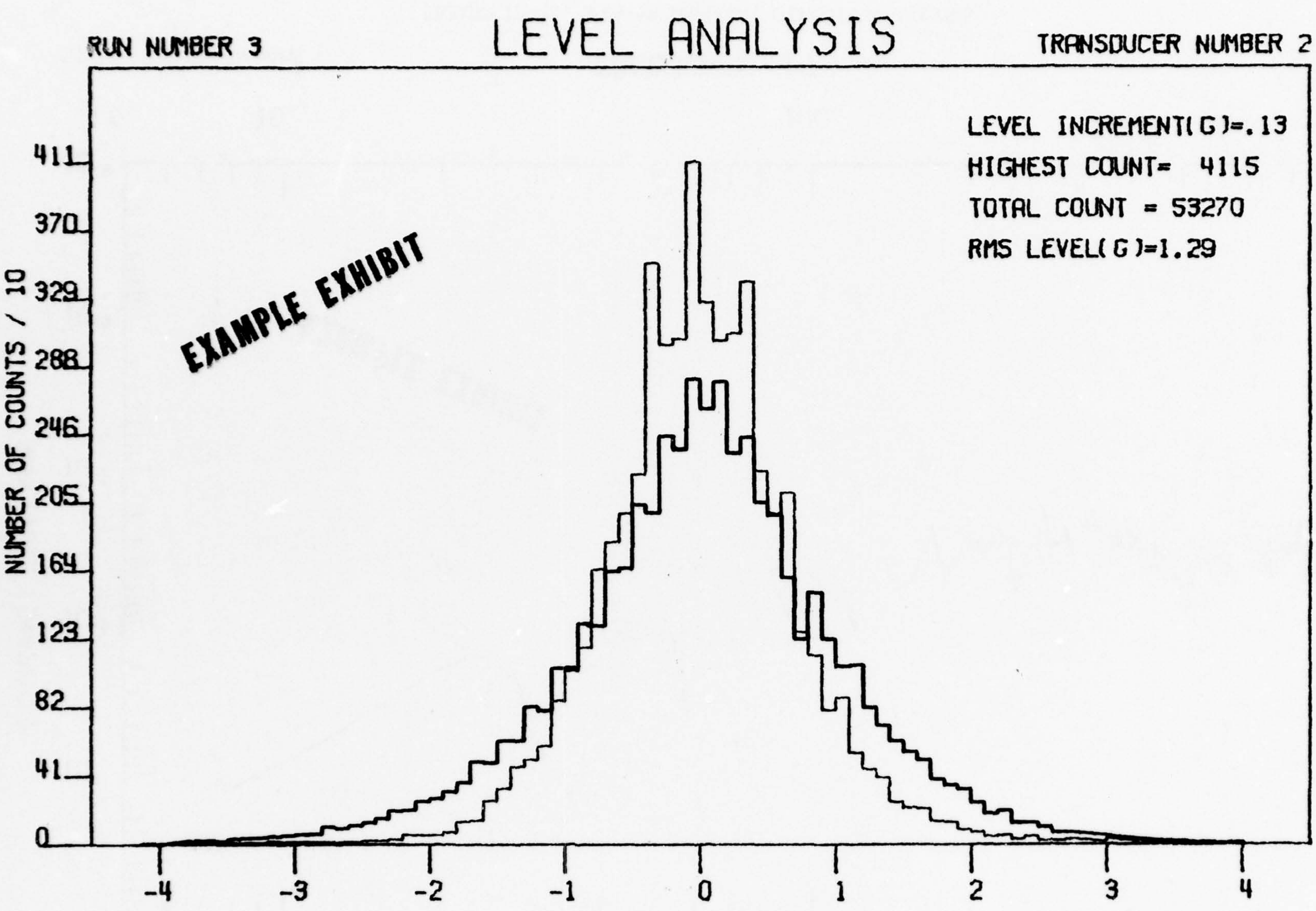
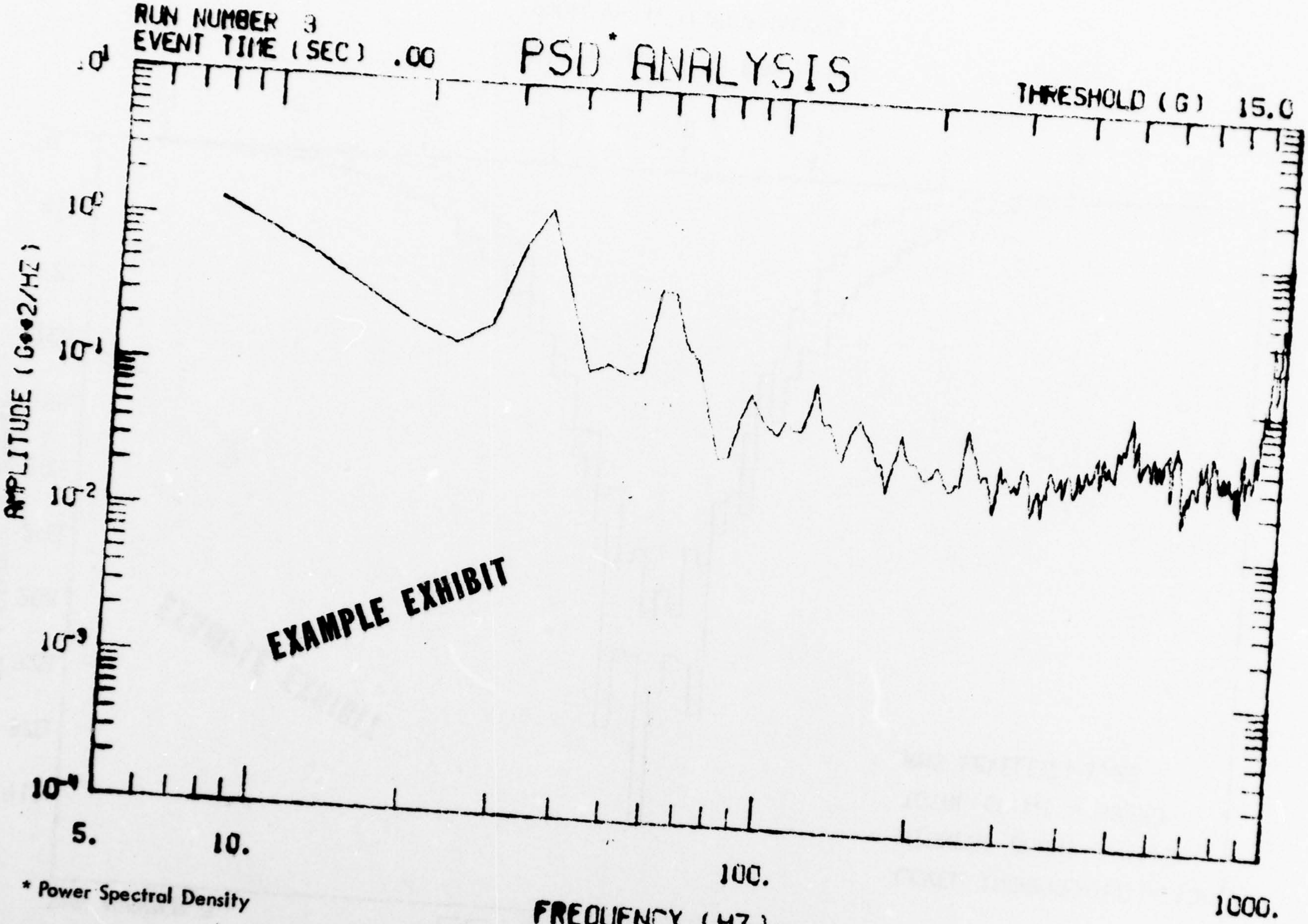


FIGURE III-14. LEVEL ANALYSIS

292-531 (57)



* Power Spectral Density

FIGURE III-15. POWER SPECTRAL DENSITY ANALYSIS

shapes of the PSDs for a single boat will be the same. As more information becomes available, it may be more practical to present the information in terms of a table of parameters, such as Table III-8 and some representative PSD shapes.

Short-duration transient vibrations, whose durations are of the order of 500 msec or less, are treated as shock pulses. Periodic vibration is most easily specified in terms of the Fourier spectra of the signals as in Figure III-16.

Shock — As with vibration, shock excitation is three dimensional and also will vary from point to point within a single boat. Limited data for typical recreational boats show that level values for the center of mass above 15 g are rare occurrences in most boats regardless of boat length or wave conditions (except for very short, i.e., 5-10 msec pulses, which may be higher).

The durations of individual shock pulses within identifiable complex shock events vary from 10-100 msec for boats up to 26 ft in length. Shock events in cruisers of 42 ft and 45 ft boat length were single, smooth pulses with durations of about 200 msec or less, and levels which very seldom approach 10 g. Shock levels also decrease from bow to stern. A typical shock of 10 g at the bow decreased to 6 or 7 g amidships and 4 or 5 g at the stern.

Shock environments are specified by shock analysis, as shown in Figure III-17. The amplitudes and durations of these pulses will be formatted as in Table III-9 and are for maximum speeds or maximum navigable speeds.

Acoustic Environment — The acoustic environment of a boat at cruising speed (generated mainly by the engine and the water-hull interaction) is most conveniently specified by the overall sound pressure level (OASPL - see example exhibit, Figure III-18) and the octave band sound pressure level (SPL - see example exhibit, Figure III-19) measured on a weighted scale. These quantities are given for both onboard values and the 50 ft (15.2 m) runby values. The 50 ft (15.2 m) runby levels are those maximum levels measured by a microphone at a point 50 ft (15.2 m) away from the straight-line course of a boat travelling at cruising speed. An analysis of existing data though not presented as in the example exhibits is discussed in Section V.

TABLE III-8. PSD SHAPES AND FREQUENCES AT LEVEL CHANGES FOR BOAT LOCATIONS

PSD SHAPES		LOCATIONS				
		Bow	Amidships	Stern	Fuel Tank	. . . .
Levels	A_1					
	A_2					
	. . .					
	A_n					
Frequencies at Level Changes	f_1					
	f_2					
	. . .					
	f_n					

EXAMPLE EXHIBIT

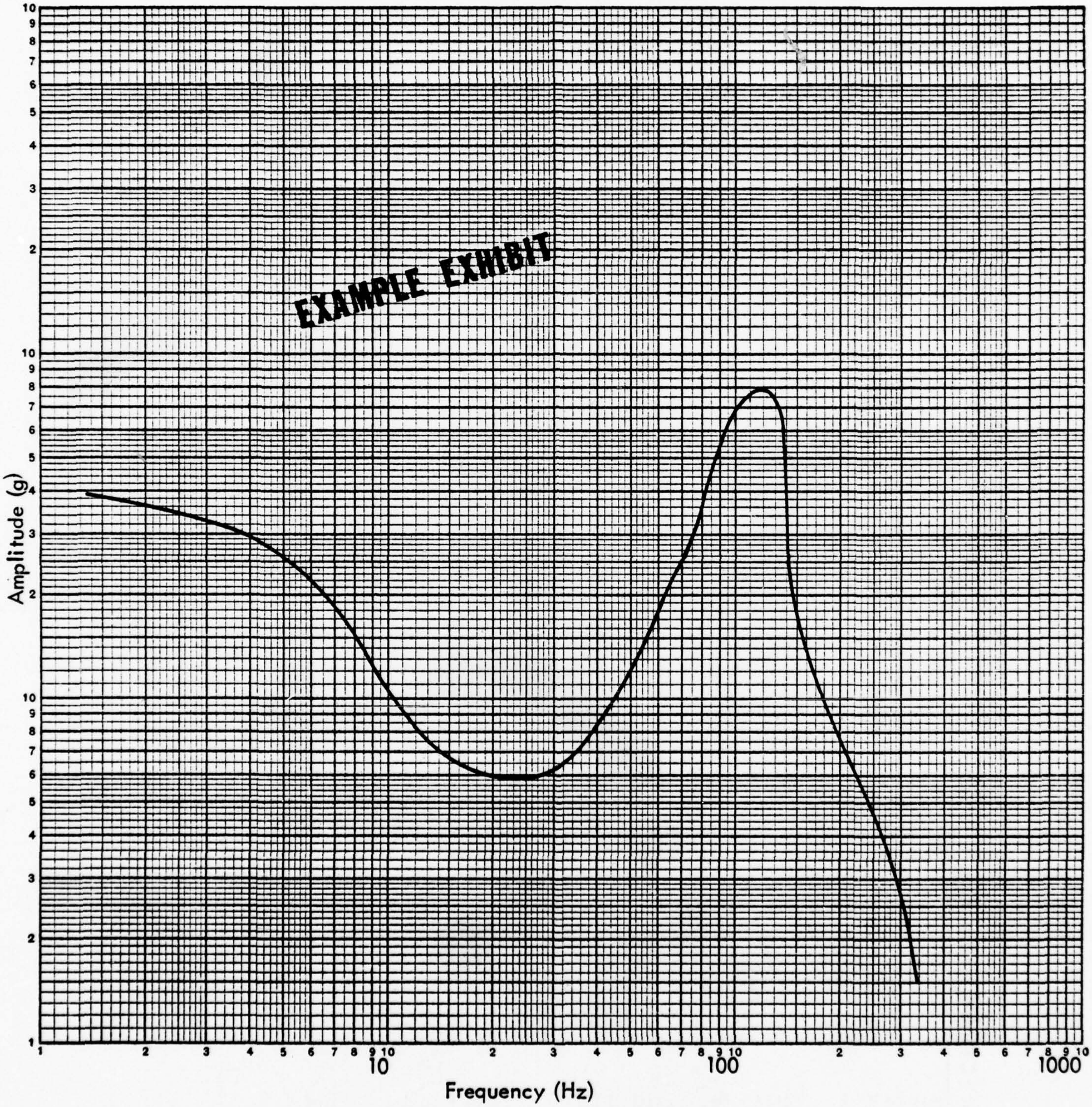


FIGURE III-16. FOURIER SPECTRA OF SIGNALS

90%

292-531 61

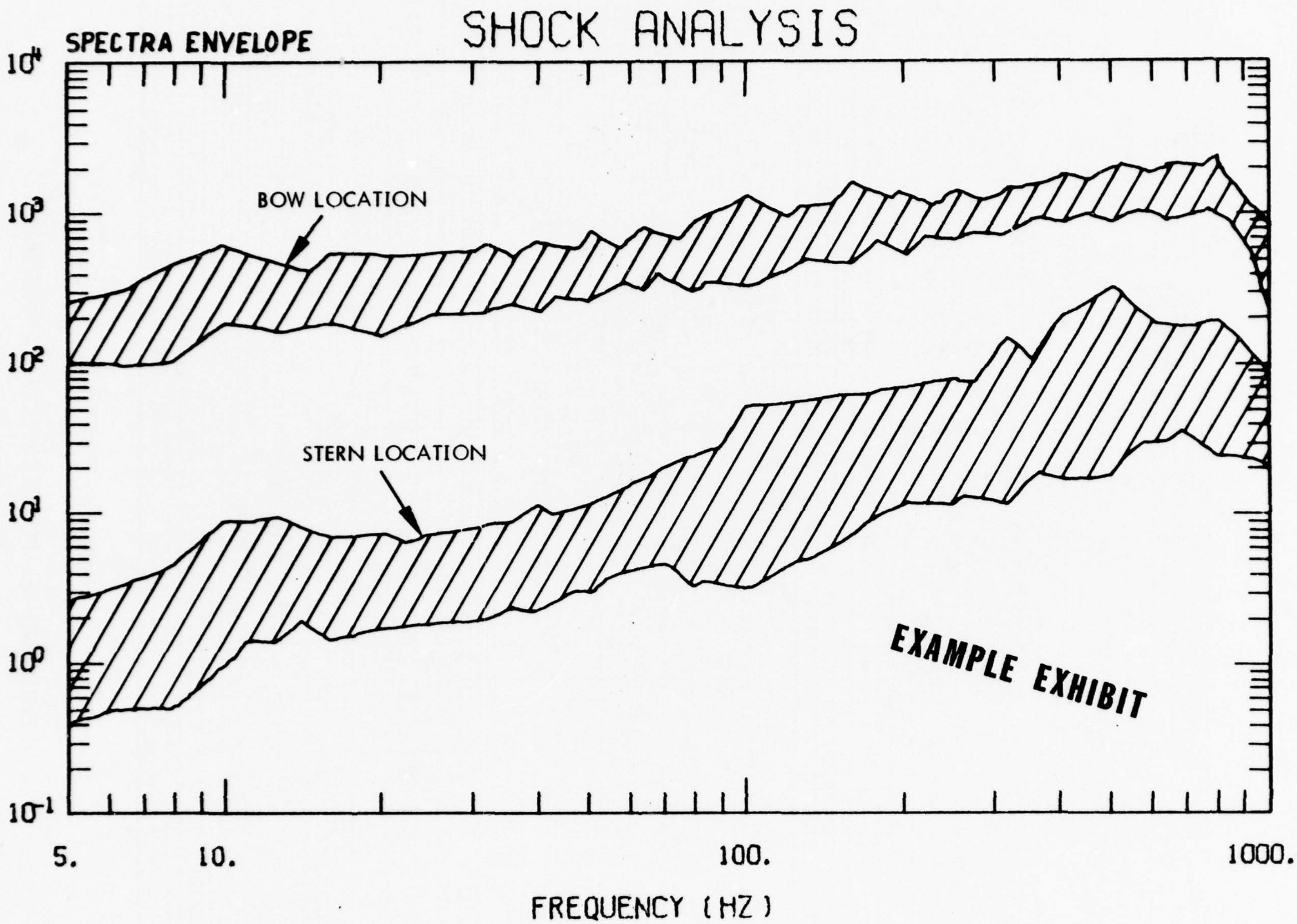


FIGURE III-17. SHOCK ANALYSIS ENVELOPES

S/S 292-531 62 64 68

TABLE III-9. SHOCK PARAMETERS FOR CLASS ____ BOATS

		BOW			AMIDSHIPS			STERN			FUEL TANK		
		Vertical	Longitudinal	Lateral	Vertical	Longutudinal	Lateral	Vertical	Longitudinal	Lateral	Vertical	Longitudinal	Lateral
AVERAGE	Amplitude												
	Duration												
MAXIMUM	Amplitude												
	Duration												

EXAMPLE EXHIBIT

OASPLs and Octave Band SPLs — These are given in terms of envelopes, as shown in Figures III-18 and III-19. The OASPLs are plotted as a function of a fractional length of a boat beginning at the stern and following the centerline of the boat forward to the bow. The data of interest would be for helm station and passenger locations for onboard data, and at a height of three feet (0.9 m) above the water level for runby data.

Fuels/Solvents/Chemical Reactions — Fuel normally used in recreational boats is gasoline. However, some percentage of the population uses diesel fuel; therefore, components which could come in contact with fuels must be compatible with the fuel required by the power plant. Larger vessels may use diesel fuel but also use gasoline for auxiliary equipment such as electrical generators.

Other chemical compounds such as bilge cleaners could prove harmful to subsystem components. In boat design/construction, components that are sensitive to such compounds should be located away from areas where used or protection should be provided.

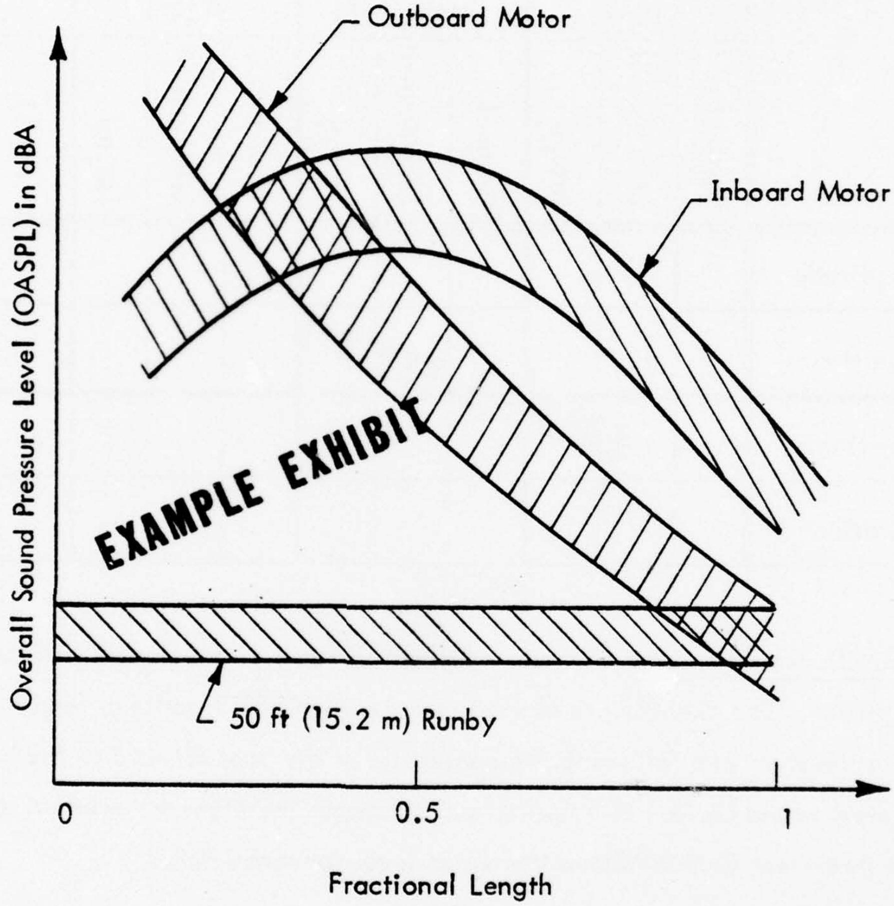


FIGURE III-18. OASPL FOR (L,HP)

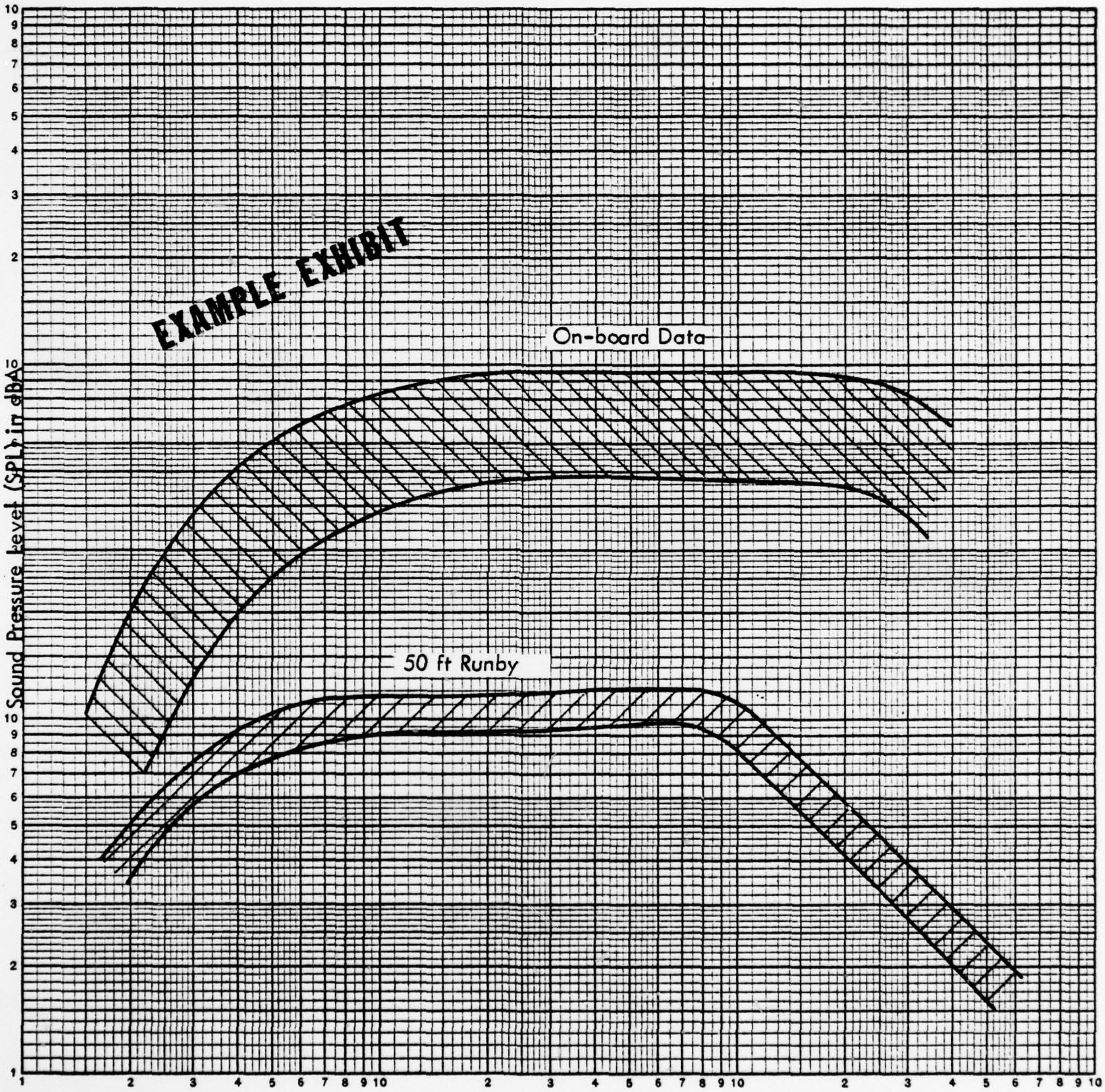


FIGURE III-19. OCTAVE BAND SPL FOR (L,HP)

5/5

292-531 65

67

Battery acid is corrosive to aluminum and steel hulls and could cause minor damage or degradation to some boat components. The designer should take this potential hazard into consideration when locating components in the vicinity of the battery or in locating the battery itself.

Temperature — Induced internal heat is generated by the boat engine. Ventilation, as well as reducing the hazard of an explosive vapor buildup in the engine compartment or bilge, also allows the engine heat to escape. In certain types of equipment, high temperature causes degradation and, thereby, increases their proneness to fail. In items of complex construction, binding of parts may also result due to differential expansion of dissimilar materials. Rubber, plastic, and plywood may tend to discolor, crack, bulge, check, or craze. Closure and sealing strips may partially melt and adhere to contacting parts. In metal hull boats, the the hull somewhat acts as a heat sink, thereby enabling some heat to be dissipated to the water or air. The plastic and wood hull boats that have a low heat transfer capability absorb the effects of the induced heat as do components located within the engine compartment. Every effort should be made to design for heat removal and dissipation.

REFERENCES

1. Wulfsberg, R.M. and D.A. Lang. Recreational Boating in the Continental United States in 1973: The Nationwide Boating Survey. The U.S. Coast Guard Office of Boating Safety. Washington, D.C. October 1974. NTIS No. AD-A000-471.

SECTION IV –
ACQUIRED INDUCED ENVIRONMENT DATA FOR 1974 AND 1975

1.0 INTRODUCTION

The data presented in this section was compiled from tests carried out in 1974 and 1975. Therefore, the data is reported separately. The data for 1974 is presented in Section IV and Appendix A. The 1975 data is contained in Section IV and Appendix B.

The intent of the 1974 work was to gather pounding data for recreational boats operated in heavy seas and to utilize all available data to formulate new fuel tank shock compliance test parameters. Specifically, the data reported were for the following boats:

- 26 ft (7.9 m) Stamas
- 21 ft (6.4 m) Seabird
- 15 ft (4.6 m) Glastron Swinger
- 42 ft (12.8 m) Hatteras Yacht
- 45 ft (13.7 m) Hatteras Yacht

2.0 DATA COLLECTION AND REDUCTION (1974)

2.1 Small Boat Data Collection

The data described in this section were taken for:

- 26 ft (7.9 m) Stamas; one run,
- 21 ft (6.4 m) Seabird; four runs, and
- 15 ft (4.6 m) Glastron Swinger; one run.

Wave heights for these runs ranged up to six feet (1.8 m).

2.1.1 Instrumentation and Data Collection

Each test boat was instrumented with five transducers to acquire acceleration, roll, pitch and yaw data. A Schaevitz Model LSBG 39 DC accelerometer was installed in the bow, amidships, and stern (see Figures IV-1, IV-2, and IV-3).

The Murphy gyro, Model VG24-0801-1, was located in the approximate center of the boat to obtain roll and pitch data. The transducer output signals were conditioned by the Wyle boat instrumentation package. The gyros and signal conditioning equipment were housed in two aluminum boxes, as shown in Figure IV-4.

The data were recorded on a Lockheed Electronics Model 417 FM tape recorder. One channel of the recorder was used for a voice track to record test conditions, event time, etc. A Kustom Electronics Model TR6 radar unit was used to accurately measure the speed of each boat.

The instrumentation system and transducer installations on the Hatteras yachts were the same as installed on the small boats with the following exceptions:

- Two Endevco Model 2272 piezoelectric accelerometers were installed on the main longitudinal stringers in the engine compartment to acquire engine vibration data.
- The radar unit was not used to measure boat speed.

RESCREEN & SQUARE HALFTONES

7a

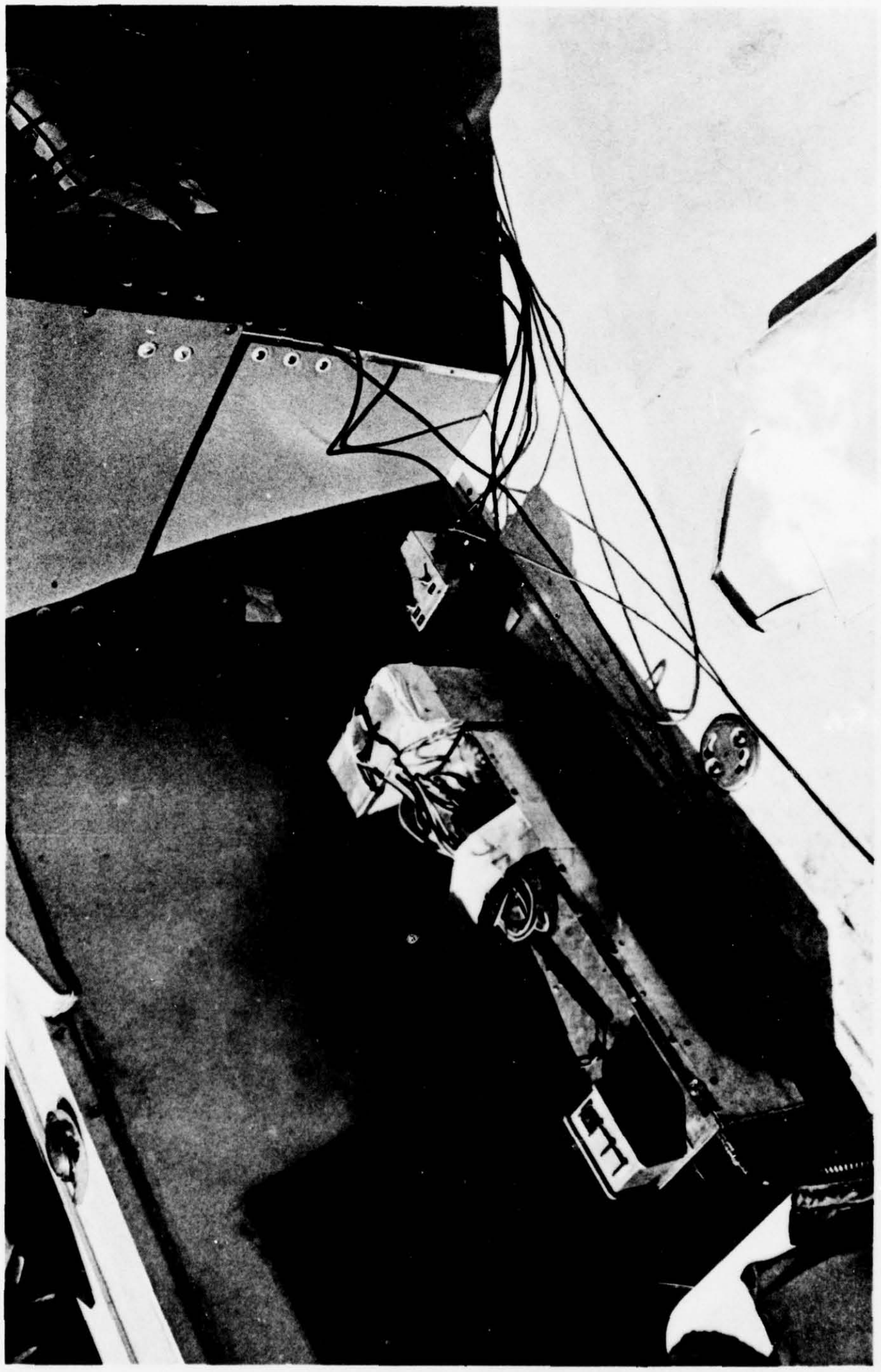


FIGURE IV-1. BOW ACCELEROMETER INSTALLATION

71

8a

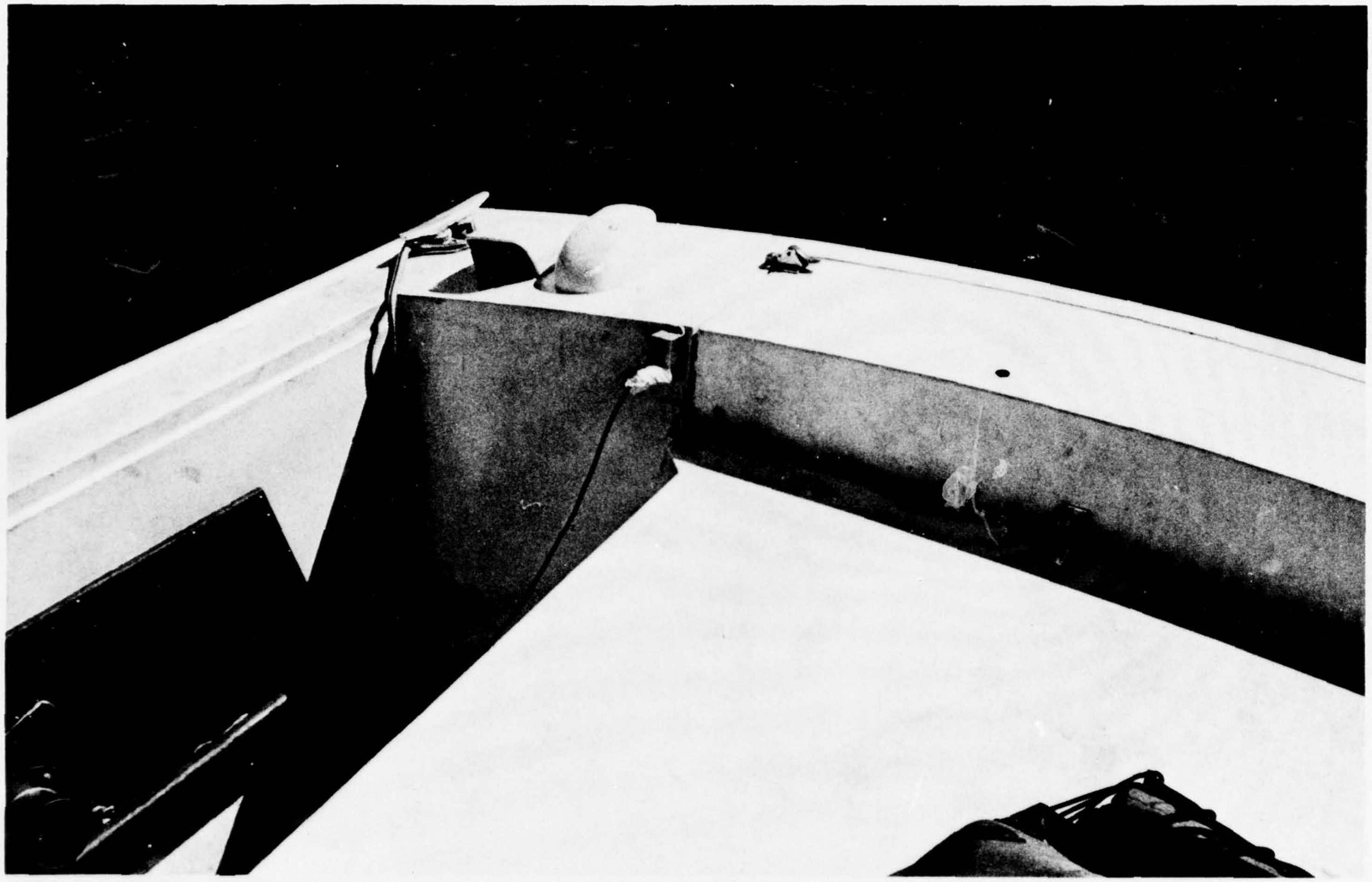


FIGURE IV-2. AMIDSHIPS ACCELEROMETER INSTALLATION

9a

GURE IV-3. STERN ACCELEROMETER INSTALLATION

RESCREEN & SQUARE HALFTONES

10a

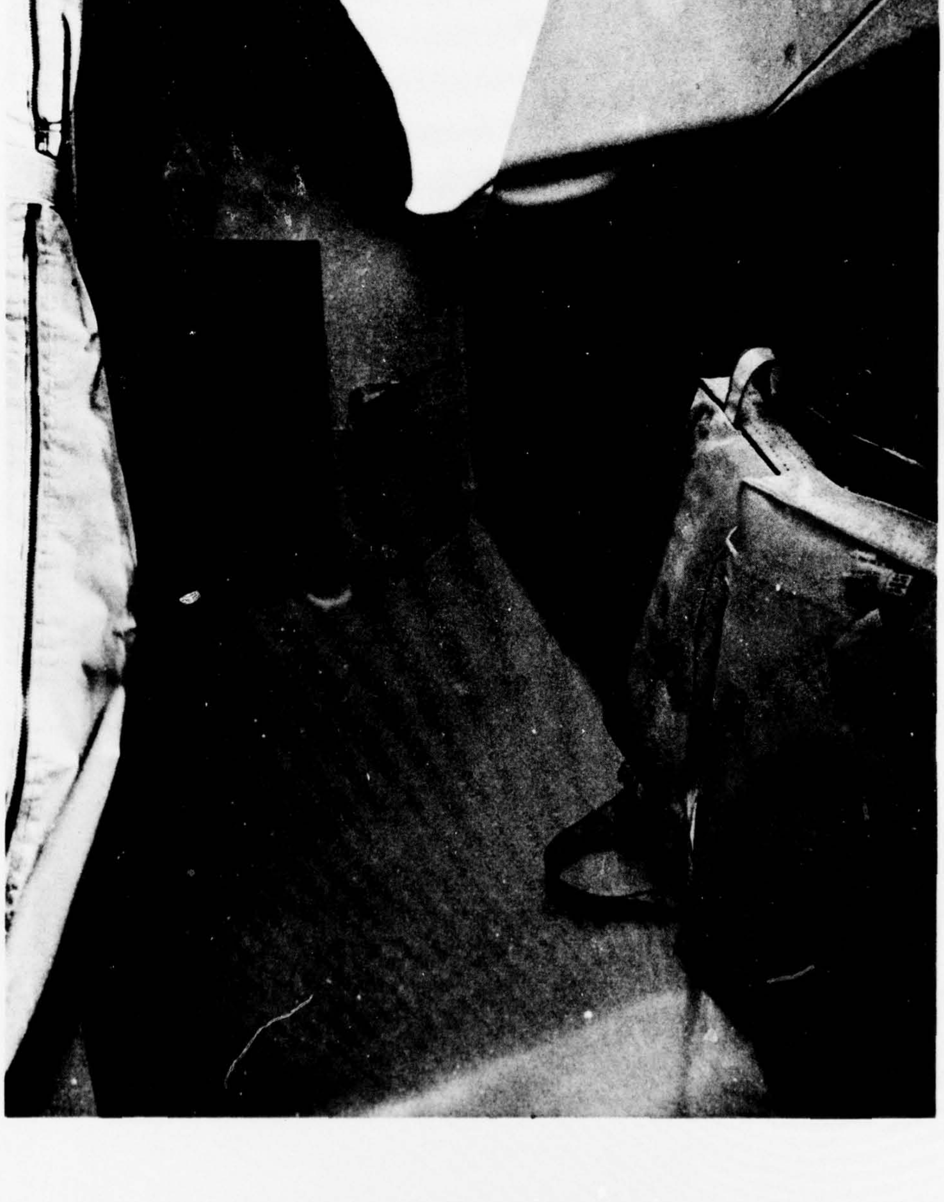


FIGURE IV-4. BOAT INSTRUMENTATION PACKAGE

2.1.2 *Data Reduction*

The data was recorded on FM tape during the test runs and then played back onto an oscillograph record for a "quick look" at the data. For the majority of the data runs it appeared that the FM recorder used had not been sufficiently well shock-mounted. High amplitude shocks had the effect of changing the tape speed and rendering the data irretrievable. All accelerometer readings also displayed high frequency components which appeared to be due to vibration.

Those data runs for which the recorder was shock mounted well enough were again played back onto an oscillograph record with the vertical accelerometer data being played through an analog low pass filter to remove all frequencies above 60 Hz. Although the filters eliminated high frequency signals, they also introduced a 60 Hz hum onto the data signals with a double amplitude of about 1 g. This hum was smoothed out by hand for each event. The height in g and the envelope duration in milliseconds of each discernable shock event were then measured.

The exact shapes of shock envelopes showed a wide variation, as would be expected. These are discussed for each boat. It is also to be noted that events would occasionally occur at one end of the boat for which there were no corresponding measurable events at the other end.

Appendix A, Reduced Data for 1974, summarizes the small boat data. Figures A-1 through A-4 present the Stamas data, while Figures A-5 through A-20 display, run-by-run, the Seabird data. The data derived from the Glastron Swinger is contained in Figures A-21 through A-24. Figure A-25 is a histogram of peak value of a shock event times shock duration for all of the small boat data collected. Hatteras yacht data is presented in Figures A-26 through A-29. Reduced UL data is provided in Figures A-30 through A-33. AMF data is shown in Figures A-34 through A-37.

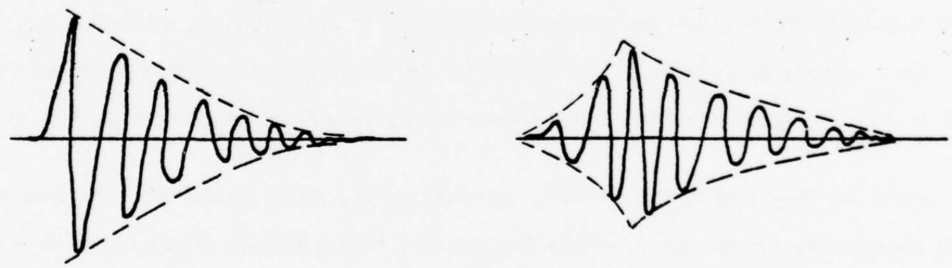
2.1.3 Twenty-Six Ft (7.9 m) Stamas Test Data

The pounding data for the Stamas craft is rather complex. Many of the forward shock events were composed of pulses and/or vibration, and almost all of those events recorded in the stern area appear to be transient vibrations. Appendix A, Figures A-1 through A-4 contain Stamas shock data.

Some of the more readily visable, identifiable characteristics of the data records are:

- Shock envelopes of the bow events, for the most part, are distorted sawtooth, half-cycles such as sketched below.

- The shock events in the stern appeared to be exponentially damped vibration such as shown in the sketch on the following page. Half-cycle times ranged from 10 to 70 msec.



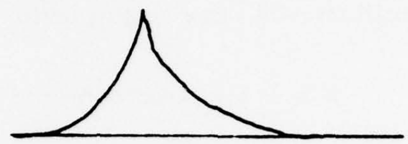
- Identifiable shock event lifetimes ranged between 100 and 500 msec.
- Peak amplitudes ranged from 1.75 g to 21.5 g.

2.1.4 Twenty-One Ft (6.4 m) Seabird Runs

The pounding data for the Seabird craft has much less vibration in it than did the Stamas data. There was less of a tendency for an event to appear as a sum of identifiable motions, such as vibration or distinct, separated pulses. High-level events, however, tended to be separated into one, two, or three pulses which decreased in amplitude as the event grew older. The peak values of each event plotted against the duration are shown in Figures A-5, A-9, A-13, and A-17 of Appendix A.

Observations drawn from the data are:

- The most common shape for a shock event was as sketched below:



  Detailed numerical analysis might show the buildup and attenuation curves to be roughly exponential.

- Event lifetimes were of the order of 100 to 500 msec.
- Measurable event peak values ranged from 1 g to 19 g.
- Individual, identifiable pulse widths were estimated to be 70 msec or less.
- The data records did not always show a measurable stern event for every bow event.

2.1.5 Fifteen Ft (4.6 m) Glastron Swinger Data

The Glastron test run did not yield data which can be regarded as reliable, as did the data obtained from the previous test runs discussed. Judging from the oscillograph records, the recording accuracy worsened as time into the run progressed, rendering lifetime estimates and height measurements of extremely doubtful reliability. No stern events were reduced since this channel began to record what appeared to be a random vibration which was judged to indicate a malfunctioning of the recording of that channel. In addition, some of the longer duration events could be considered as superpositions of shorter duration events. Figure A-21 of Appendix A is a plot of peak values of the events against duration of events.

Some of the characteristics of the Glastron data are:

- The short duration pulses and vibration present in the Stamas and Seabird data were absent for the most part.
- There seemed to be no real preferred pulse shape except to be approximately triangular.

2.2 Hatteras Yacht Data

In addition to the small boat data described previously, Wyle Laboratories instrumented two Hatteras yachts, a 42 ft (12.8 m) yacht and a 45 ft (13.7 m) yacht, and collected pounding data for severe water conditions with wave heights up to 12 ft (3.7 m).

2.2.1 Instrumentation and Test Runs

The Wyle instrumentation package and associated transducers were installed on each yacht to acquire accelerations, roll and pitch data. The data were acquired on an FM tape recorder. Acceleration data were acquired by AMF personnel on a real-time oscillograph. Event time was noted on each system for future data correlation. Four test runs were made of each yacht. The duration of each run was approximately one minute. Refer to Section 2.1.1 for instrumentation equipment and transducer locations.

2.2.2 Forty-Two Ft (12.8 m) and Forty-Five Ft (13.7 m) Hatteras Yacht Data

The oscillograph records for these runs showed two complications with respect to data reduction:

- The data records for the 45 foot boat exhibited a beating of the 60 Hz hum introduced by the analog filter.
- The tape recorder was not sufficiently shock-mounted to allow the accurate recording of the strongest shock events. However, in each case the peak value of the shock appeared to have passed before the tape recorder was affected.

Despite the above difficulties, values for duration and peak were obtained for a total of about 50 pulses. These data are summarized in Figures A-26 through A-29 of Appendix A.

General comments about the data itself are:

- When the 60 Hz hum was smoothed out, the common shapes a shock event could take appeared to be

The slight vibration at the end of the pulse might be due to structural rebound of the deck or whatever component to which the accelerometer was attached.

- All but three measured events had lifetimes in the range of 200 to 500 msec.
- All peak values of measured events were in the range of 1 g to 8 g.
- Pulse shapes appeared to be fairly free of complex structure.

3.0 COMPARISON WITH OTHER DATA

3.1 Small Boat Data

The shock data collected by UL were for the following boats:

- 13 ft 3 in. (4 m) Fisher-Price Utility Boat (Boston Whaler)
- 18 ft 6 in. (5.6 m) Mako Marine
- 15 ft 5 in. (4.7 m) Mitchell Utility
- 17 ft 6 in. (5.3 m) Thompson
- 34 ft (10.4 m) Webers Cove Cruiser

Figures A-30 and A-33 of Appendix A summarize this data in the same form as the Wyle data.

The data for small boats obtained by Wyle Laboratories differs from the data obtained by Underwriters Laboratories mainly in two aspects:

- Except for the 34 ft (10.4 m) Webers Cove, the sea states for which the UL data were obtained were much calmer than the sea state for which the Wyle data was taken.
- The Wyle data reflects the duration of the whole shock event, while the UL data apparently is only for a single peak in the event.

The recorded wave heights for the UL test runs were from 8 in. to 12 in. (20.3 to 30.5 cm) and 18 in. (45.7 cm) wakes for the small boats. Wave heights for the Weber Cove test run were from two to four feet (0.6 to 1.2 m) which is comparable to the wave heights during the Wyle test runs for small boats.

When measuring the duration of a shock event the time interval chosen was that over which the signal trace appeared to show a definite deviation away from the base line trace. Evidently, the UL data only measures the widths of one or more particular peaks in the total shock event. When the UL signal traces are examined, some of the signals could be classified as transient vibrations.

Figure A-30 is a plot of the peak value in g versus the duration time of the forward vertical pulses as recorded on the UL data sheets. Both the range of the peak values and the peak duration compare well with individual peak heights and durations noted for the Stamas and Seabird runs. The Stamas and Seabird duration times for individual peaks are somewhat longer than those obtained by UL but are of the same order of magnitude.

3.2 Hatteras Yacht Data

As indicated previously, AMF Corporation also acquired forward vertical shock data on the test runs for which Wyle Laboratories acquired data (Reference 1). AMF also acquired data for additional test runs of the 45 ft (13.7 m) Hatteras yacht. The AMF reduced data are summarized in Figures A-34 to A-37 of Appendix A. When compared to the Wyle data, the AMF data indicates slightly higher peaks and shorter durations. The reasons for this are:

- Again, as stated previously, the tape recorder with which the data was recorded was not sufficiently well mounted to withstand the highest level shocks and keep the tape speed constant. Since it was an FM recorder and the speed variation was unknown, data on the highest level shocks were irretrievable.
- The AMF estimation of the duration was based on the ABYC "envelope" requirement in that the duration was estimated as the duration of a square wave of amplitude approximately 70% of the peak acceleration whose impulse (amplitude times duration) was equal to the actual shock event ($\int_0^T a(t)\, dt$, where T = duration of event). The Wyle reduction, on the other hand, measured the total duration of the shock event and thus could easily be 200 to 300 msec longer for the same event.

In addition to the above comments, it is to be noted that the data reduction here included apparent events of levels lower than 2 g where the AMF reduction ignored these events.

In light of the above discussion, it is felt that the reduced data presented here compared rather well with the reduced data of AMF.

4.0 ACQUIRED INDUCED ENVIRONMENT DATA (1975)

Work described in this section was directed toward the development of the definition of the induced environmental factors of shock and vibration on a typical recreational boat. Two boats were, initially, selected and instrumented - an 18 ft (5.5 m) inboard/outdrive and a 16 ft (4.9 m) outboard. Equipment failures resulting from the environment reduced the credibility of some data collected and entirely prevented other data from being derived. The data analysis was, therefore, limited to shock and vibration data. The nature of the test equipment failures indicated that further repetition of these tests would also result in failure unless specifically designed test systems and recording devices were developed and used. Strain gage instrumentation and collected data is available for future work. Figures IV-5 and IV-6 show the two instrumental boats.

FIGURE IV-5. EIGHTEEN FT (5.5 M) INBOARD/OUTDRIVE

FIGURE IV-6. SIXTEEN FT (4.9M) OUTBOARD

• The radar unit was not used to measure boat speed.

5.0 INSTRUMENTATION

The primary objective for instrumentation was to acquire shock/vibration data for each boat at three different water conditions. Secondary objectives included strain gage and temperature data for at least one of the boats. The inboard/outdrive (I/O) was considered the primary boat and was instrumented with shock, vibration, strain and temperature sensors. The outboard (OB) was instrumented with shock/vibration sensors only. During data acquisition for each boat, the other boat was used as a safety boat.

5.1 Type/Location - I/O

Instrumentation location points are indicated below; instrumentation type and reference figures are indicated in Table IV-1.

- Location 1 - Bow centerline
- Location 2 - Starboard bow at water interaction region
- Location 3 - Port gunwale 1/3 of length from bow at the waterline
- Location 4 - Midship centerline
- Location 5 - Aft centerline next to motor mounts
- Location 6 - Control console
- Location 7 - Fuel tank - forward plane
- Location 8 - Engine components

TABLE IV-1.

Location	Shock	Vibration	Strain	C-M Acc.	Temperature	Figure
1	X	X				IV-7
2	X	X	X			IV-8
3	X	X	X			IV-9
4	X	X	X	X		IV-10
5	X	X	X	X		IV-11
6		X			X	
7						IV-12
8					X	IV-13

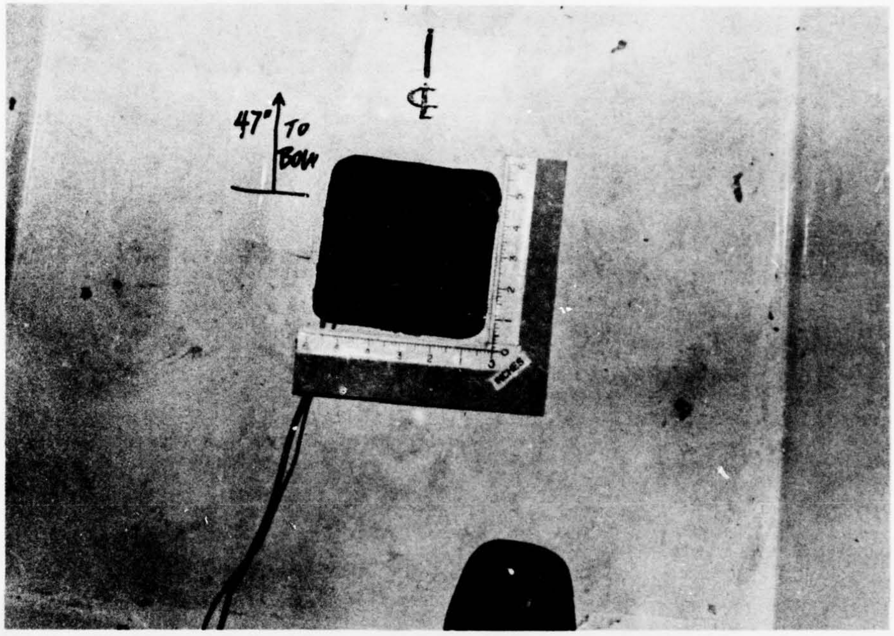


FIGURE IV-7. BOW CENTERLINE LOCATION - I/O

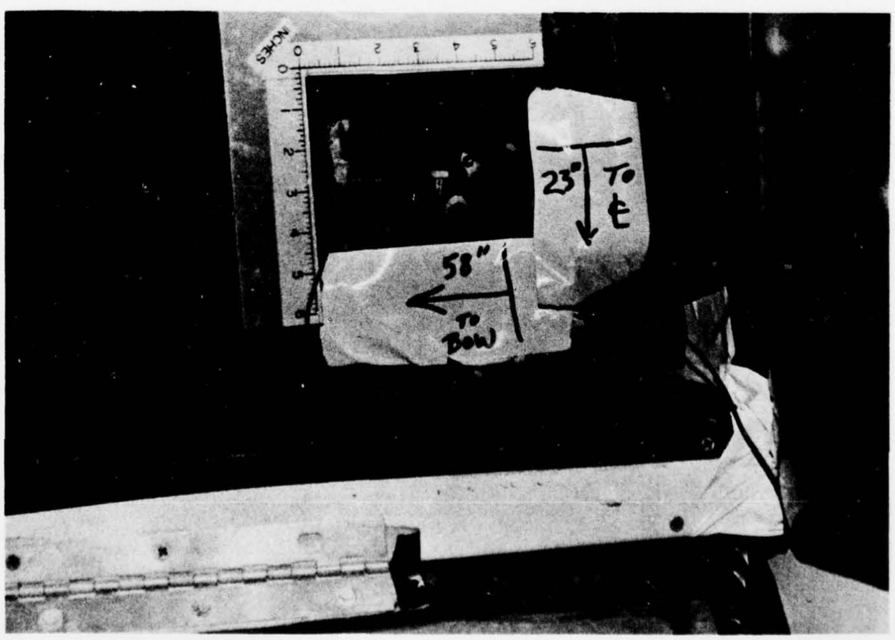


FIGURE IV-8. STARBOARD BOW LOCATION - I/O

RESCREEN & SQUARE HALFTONES
15a

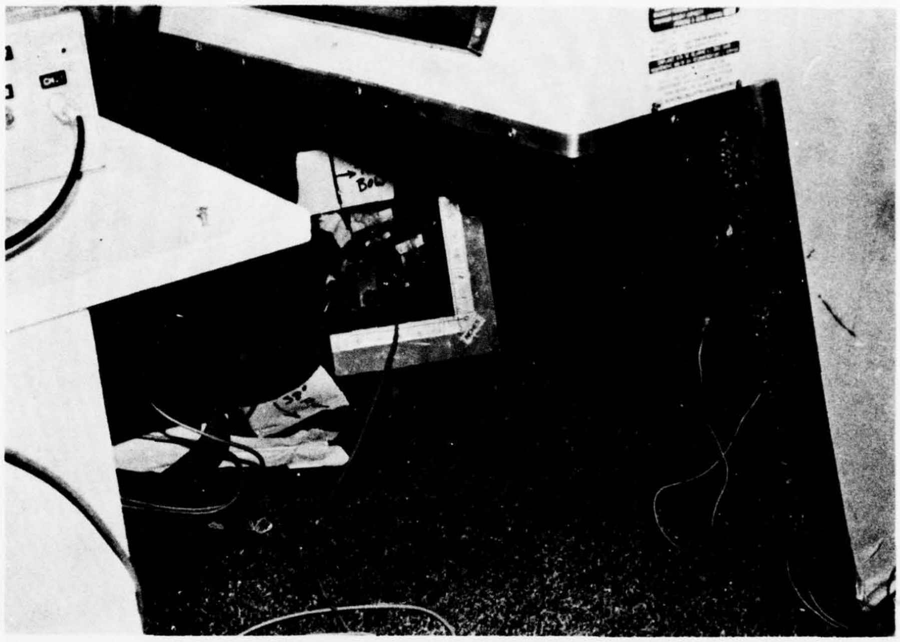


FIGURE IV-9. PORT GUNWALE - I/O

RESCREEN & SQUARE HALFTONES
16a

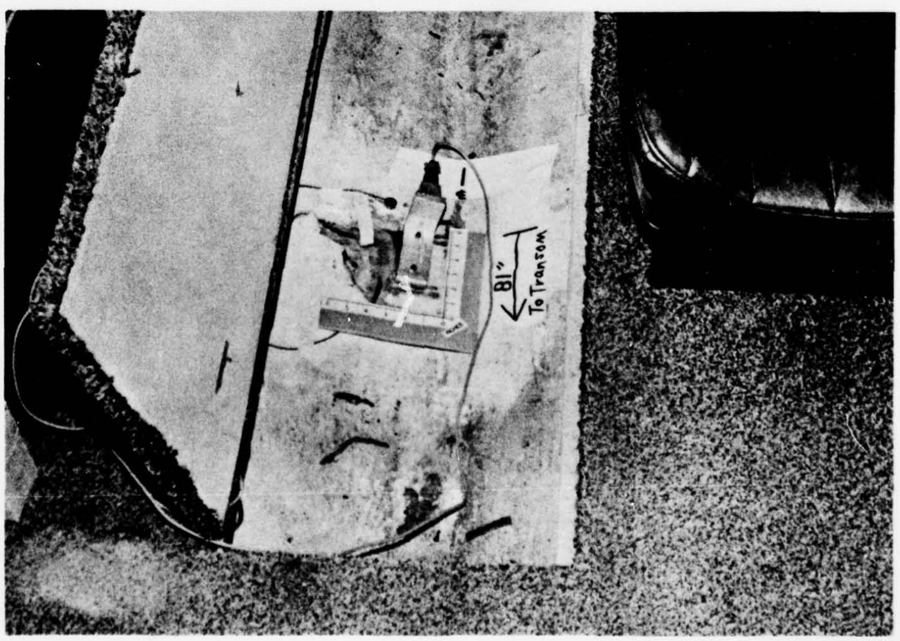


FIGURE IV-10. MIDSHIP CENTERLINE - I/O

RESCREEN & SQUARE HALFTONES
17a

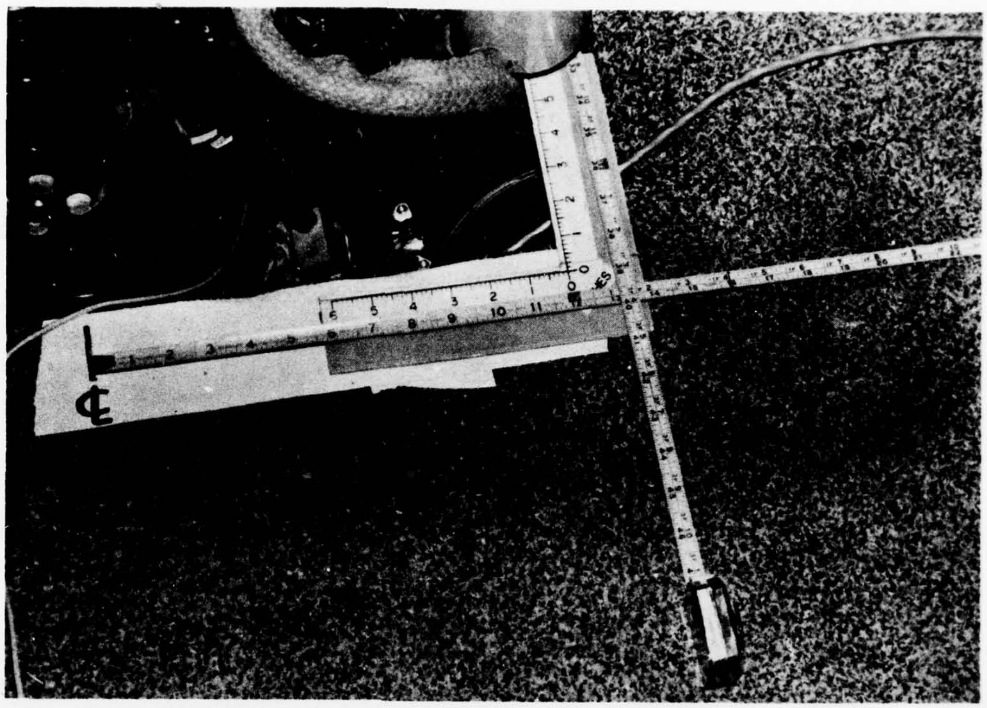


FIGURE IV-11. AFT MOTOR MOUNTS - I/O

RESCREEN & SQUARE HALFTONES
18a

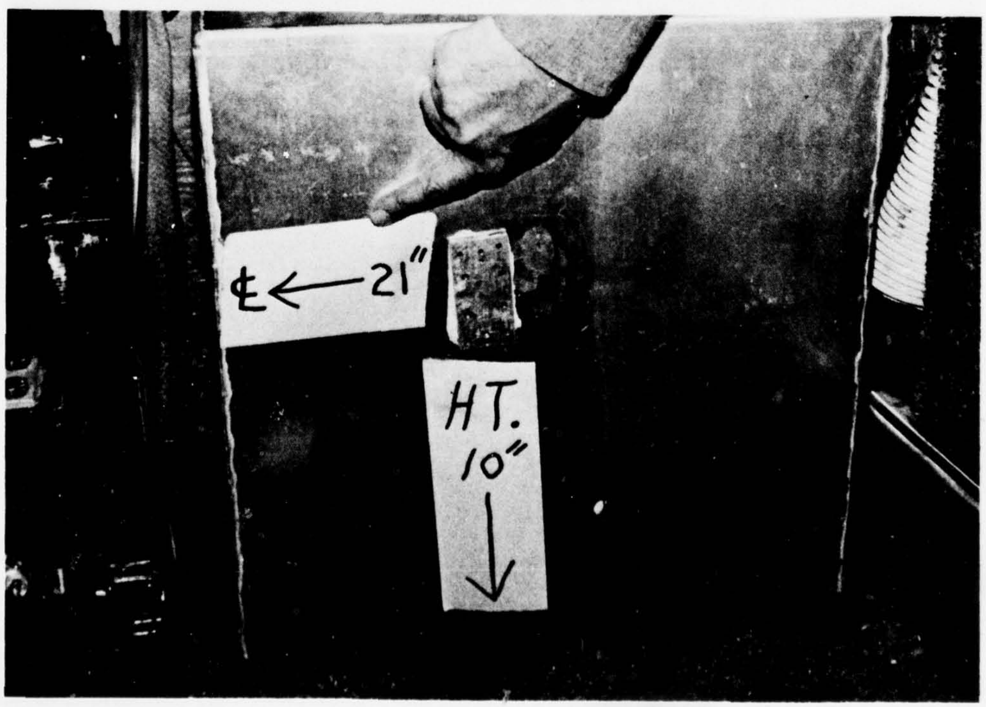


FIGURE IV-12. FUEL TANK - I/O

19a

FIGURE IV-13. ENGINE COMPARTMENTS - I/O

5.2 Type/Location - OB

Instrumentation location points are indicated below; only shock/vibration instrumentation was installed.

- Location 1 - Bow centerline - Figure IV-14
- Location 2 - Port gunwale one-third aft of bow - Figure IV-15
- Location 3 - Midship centerline - Figure IV-16
- Location 4 - Aft position - Figure IV-17

5.3 Sensors

Shock and vibration data were measured by the use of Endevco Type 2221F piezoelectric accelerometers. C-M acceleration was measured using Schaevitz Model LSBC39 linear strain gage accelerometers. The type data measured by each type accelerometer are determined by the frequency response of each type as indicated below:

- Piezoelectric - 2 Hz. to 200 KHz.
- Strain gage - DC to 150 Hz.

Figure IV-18 shows the realtive size of each accelerometer.

Temperature data were measured by the use of 20 gage copper-constantan thermocouples. Strain measurements were taken with bi-directional (transverse-longitudinal) one-quarter in. (0.6 cm) square strain gage pads.

5.4 Processing Electronics

Figure IV-19 shows the combined processing electronics package developed for subsystems data acquisition. Main power was obtained from two 12 volt electrolytic batteries arranged as a bi-polar supply. This supply was isolated from the boat electrical system to reduce system noise caused by the engine.

peak values of each event plotted against the duration are shown in Figures A-5, A-9, A-13, and A-17 of Appendix A.

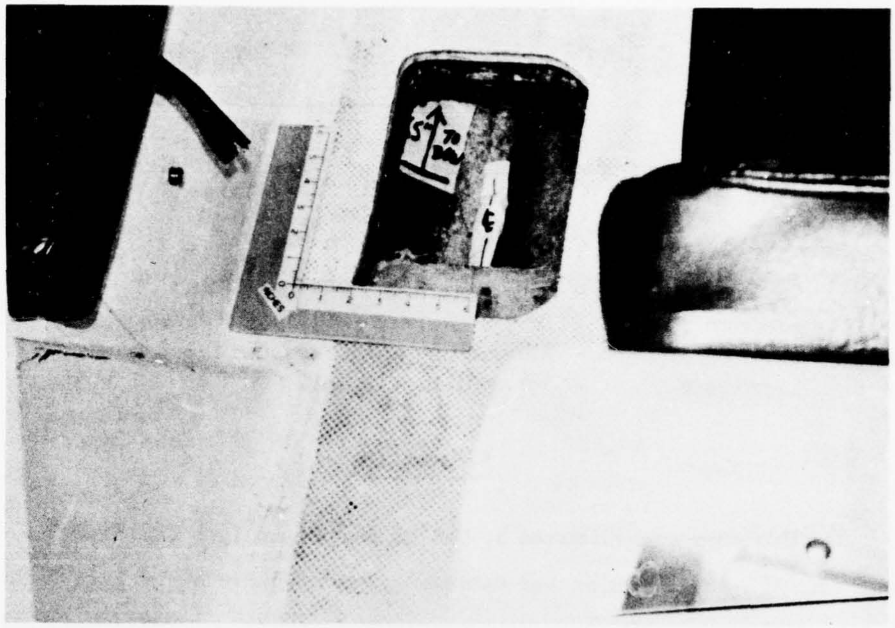


FIGURE IV-14. BOW CENTERLINE - OB

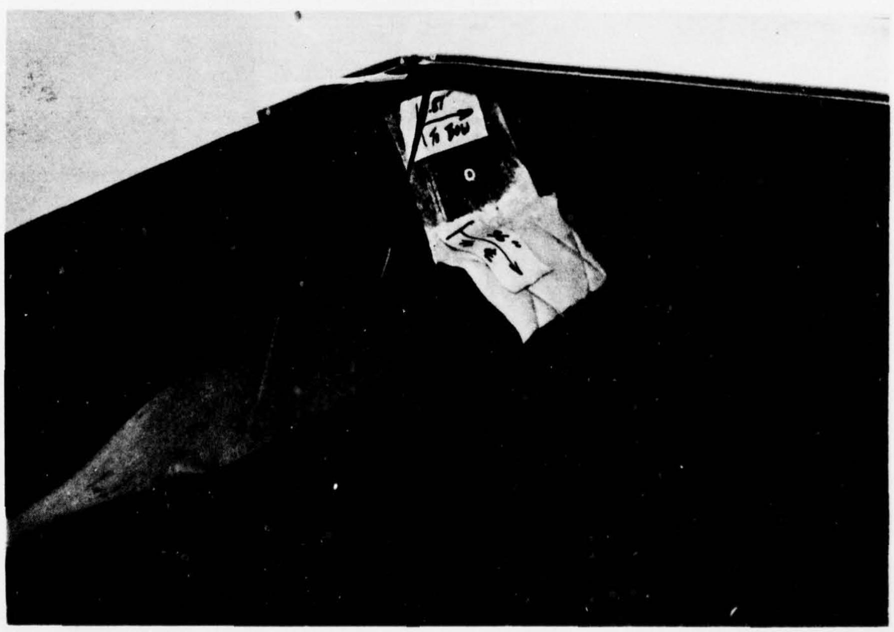


FIGURE IV-15. PORT GUNWALE - OB

- There seemed to be no real preferred pulse shape except to be approximately triangular.

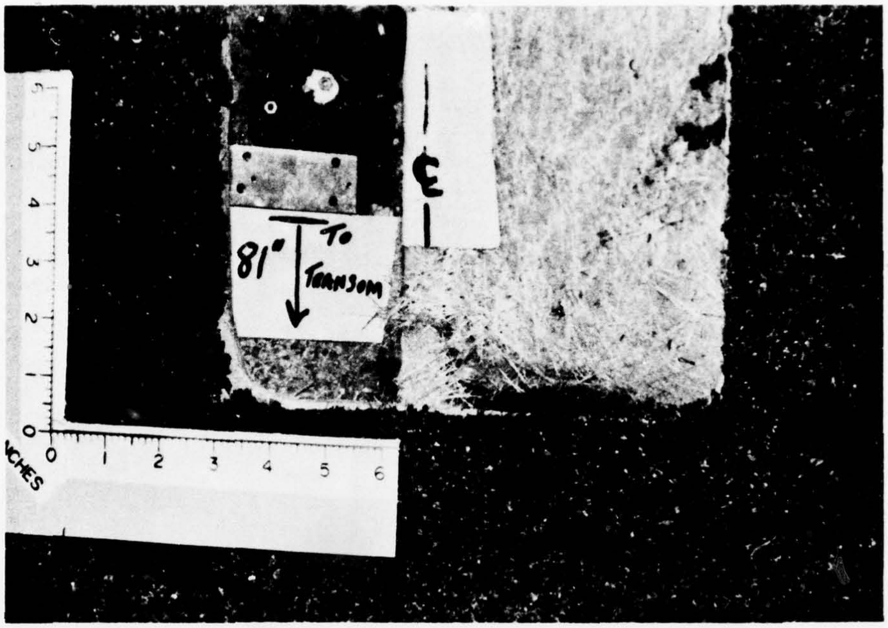


FIGURE IV-16. MIDSHIP CENTERLINE - OB

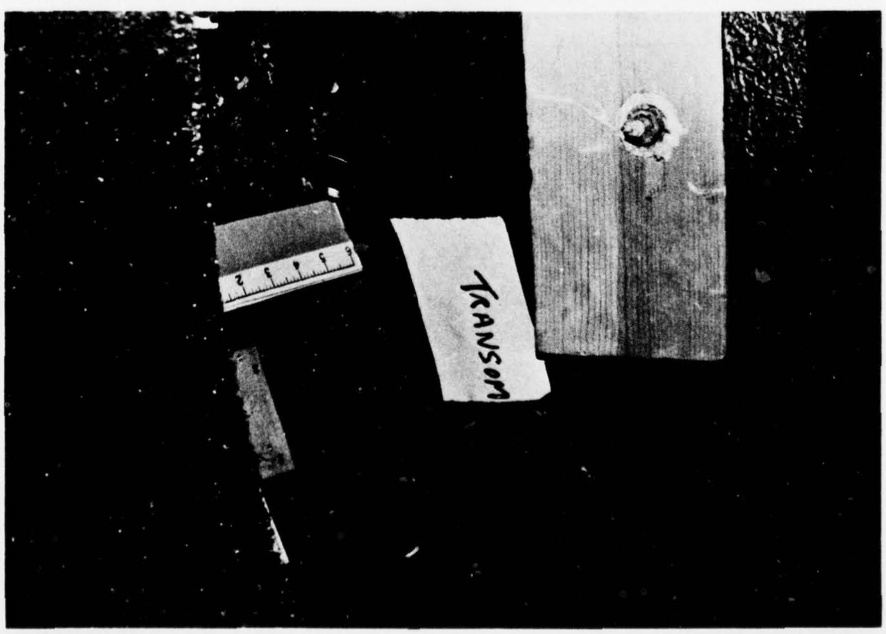


FIGURE IV-17. TRANSOM - OB

RESCREEN & SQUARE HALFTONES
24a

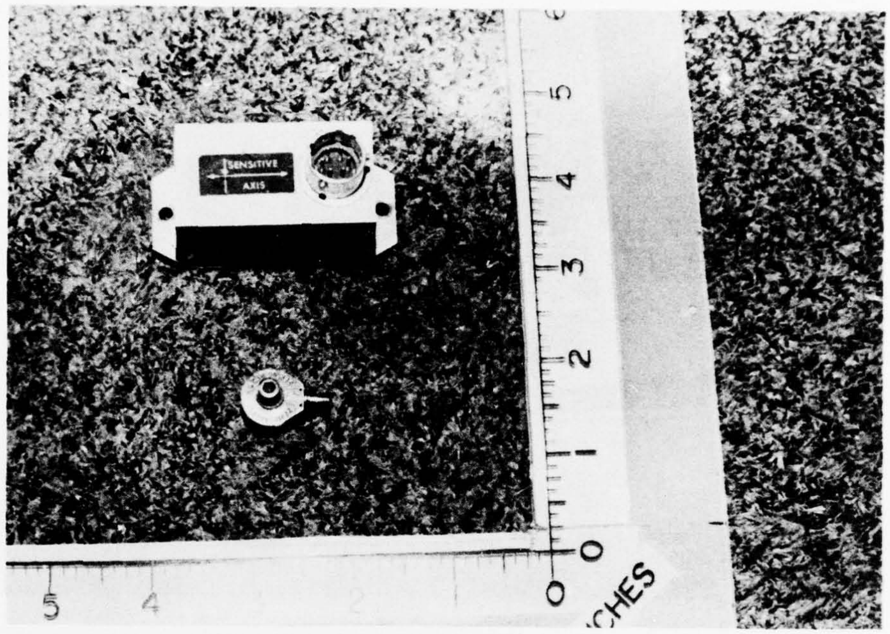


FIGURE IV-18. ACCELERATION SENSORS

RESCREEN & SQUARE HALFTONES
23a

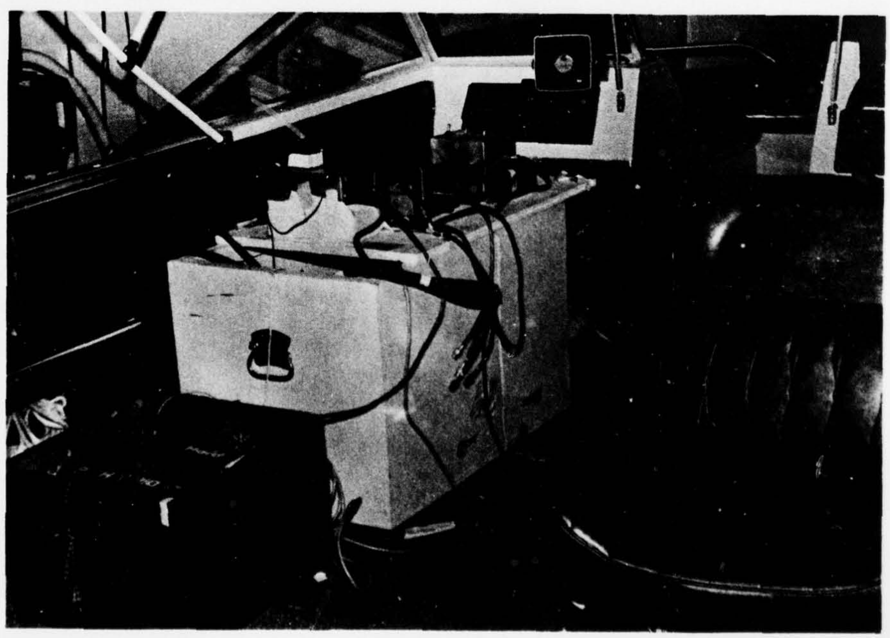


FIGURE IV-19. PROCESSING ELECTRONICS

Signal conditioning for the piezoelectric accelerometers was handled by Endevco Type 2640 charge amplifiers. Strain gage accelerometers each had self-contained amplifiers. Strain gage signal conditioning was accomplished by operational amplifiers. The conditioned signal was recorded with a Lockheed Seven Channel Model 417 FM recorder. The band pass of the recording system (DC to 1250 Hz.) was the limiting subsystem of the processing electronics package.

When the UL signal traces are examined, some of the signals could be classified as transient vibrations.

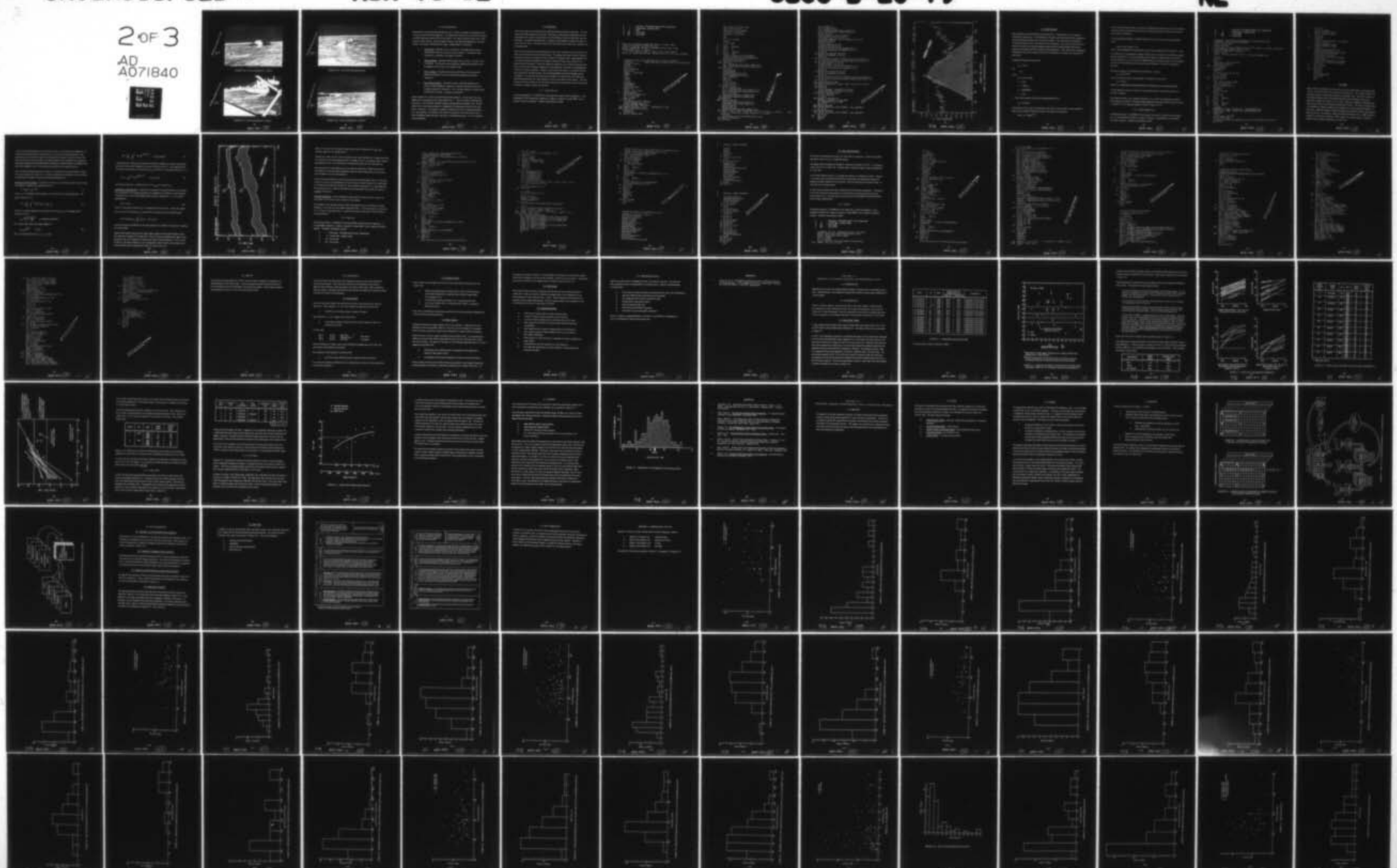
6.0 DATA ACQUISITION

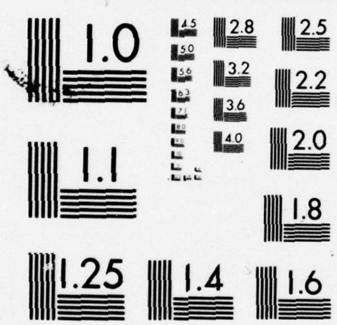
Extensive data acquisition was achieved on October 23, 1975. Several attempts to acquire data were made prior to that date, but due to adverse conditions high credibility could not be attached to the data. Severe sea-state data acquisition was attempted on October 2, 1975. The water conditions consisted of waves 6-18 in. (15.2-45.7 cm) high with 15 knot wind. Shortly into the second run, the recorder failed to operate satisfactorily. Since the actual time of malfunction could not be determined, collected data was disregarded. Figures IV-20 and IV-21 depict data acquired on October 2nd. Water conditions were considered to be too severe for typical pleasure boating, but might be encountered under extenuating circumstances. The factor limiting the use of our particular boat would be attributed to operator discomfort rather than boat instability.

With instrumentation repairs completed, data was acquired on October 23, 1975, as depicted in Figures IV-22 and IV-23. Eight data collection runs (each six minutes long) were completed and wave documentation data was acquired. Water conditions were considered just a bit rougher than ideal for pleasure boating. Water conditions consisted of 2-8 in. (5.0-20.3 cm) chop with winds less than five knots (documented by wave buoy instrumentation, Figure IV-22). Figure IV-23 depicts typical conditions during data acquisition. The data acquisition program listed in Section 7.1.1 was undertaken. Where possible, identical runs against and with the wind were made to determine the effect of different relative wave speeds along with identical runs at different boat speeds to determine severity level of impact as a function of boat speed. Boat speed was maintained at 43 mph (69.2 kph), as indicated by radar, except when slow speed (minimum planing speed) runs were made.

AD-A071 840 WYLE LABS HUNTSVILLE ALA F/G 13/10
DEFINITION AND CLASSIFICATION OF NATURAL AND INDUCED ENVIRONMEN--ETC(U)
SEP 78 DOT-CG-40672-A
UNCLASSIFIED MSR-78-12 USCG-D-20-79 NL

2 OF 3
AD
A071840




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

RESCREEN & SQUARE HALFTONES
26a

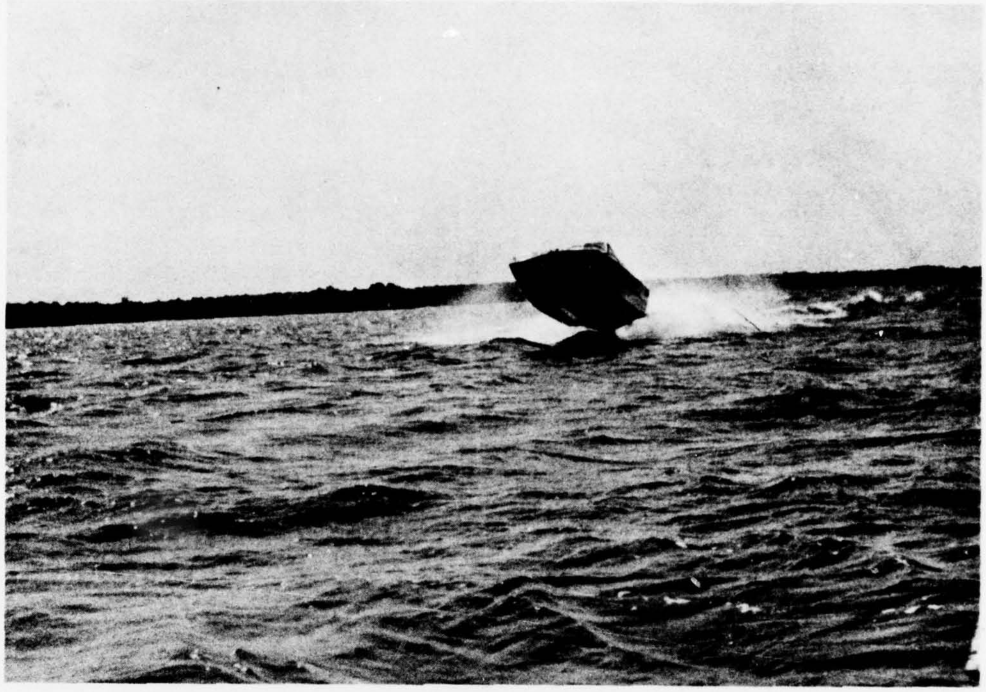


FIGURE IV-20. DATA ACQUISITION - 10/2/75

RESCREEN & SQUARE HALFTONES
27a

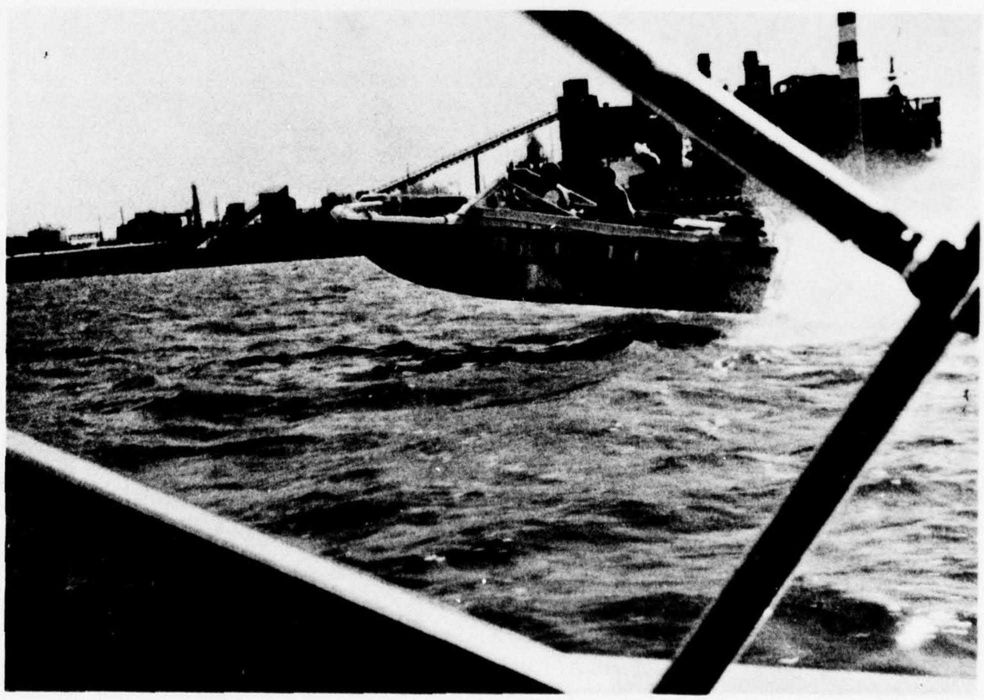


FIGURE IV-21. DATA ACQUISITION - 10/2/75

292-531 (93)

(95)

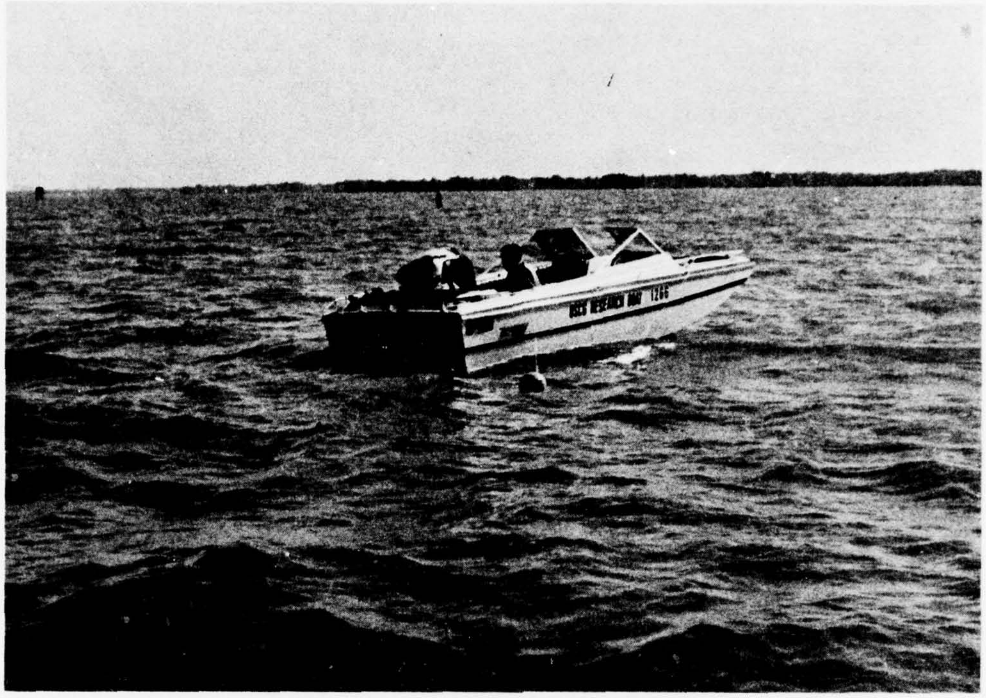


FIGURE IV-22. SEA-STATE DOCUMENTATION

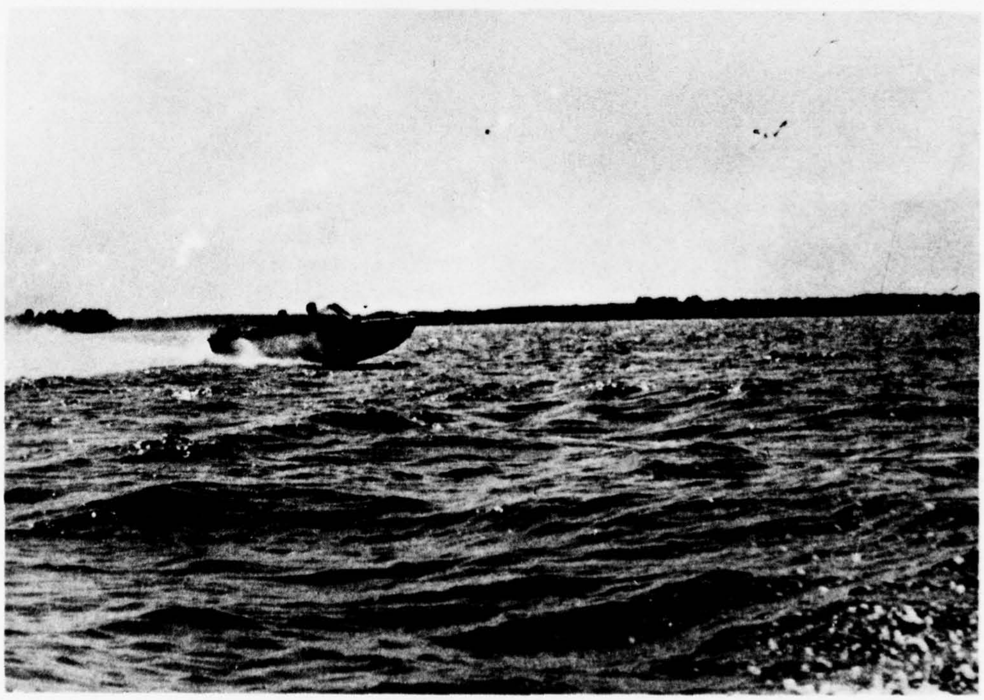


FIGURE IV-23. DATA ACQUISITION - 10/23/75

7.0 DATA REDUCTION

Data reduction was accomplished through the use of a Sigma-V computer with programs listed at the end of each following subsection. The sample rate and sensitivity for the A/D conversion was 2000 samples per second at 25 millivolts per g. Four types of analysis (level count, shock signature, shock analysis, and power spectral density) were performed depending on the type of data. The analysis techniques were chosen to address specific information:

- Level Count - describes the count distribution of recorded impacts about a specified RMS value as a function of sensor location. This analysis yields transmissivity information with regard to location.

- Shock Signature - describes the RMS energy input to the boat structure in the time domain. This analysis yields information regarding the energy that must be absorbed by the structure with regard to time.

- Shock Analysis - describes the frequency distribution of the acceleration signature recorded by the sensor and identifies predominate frequency components.

- Power Spectral Density - describes the power amplitude components of a system having 50 degrees of freedom that would be required to simulate the recorded acceleration information. This is normally applied to stationary data and identifies the power vs. frequency distribution.

Record channels No. 5 and 6 were digitized for data reduction. In each case, they were added to the inverted signal from record channel No. 7. The total amount of reduced data from each run was limited by available computer storage space and computer time. Record channel No. 5 was always attached to a piezoelectric accelerometer located at the motor mount - Location 5. This channel was used as a reference level for all other measurements, and, where possible, is analyzed in the identical time domain with record channel No. 6. Since the graphic display software is particular to the operating system, it is not included in the documentation.

7.1 Level Count

Level count analysis was performed with straightforward level detection techniques. Fifty-six thousand (56,000) samples were acquired. Each level was detected and compared to the root mean square (rms) value of the total data block (56,000 points) after the data block mean was subtracted. To simplify the presentation, a histogram was developed to display the g level in terms of the rms value. Only those values within four times the rms value were included in the data presentation.

When reviewing the data analyzed through the "level count" technique, one must realize that there are two driving forces on the datum sensors. The predominant force is the skin vibration induced by the power train system with the ringing of the fiberglass shell, superimposed on this is the shock information imposed by the impact of the boat striking a wave (Figure IV-24 depicts both driving forces). Since the vibration driving force is at a relatively constant level and is a function of the resonant frequency for each subsection of the boat, no transmissibility information is readily available. However, since wave action (shock) is initiated at the bow and transmitted aft through the boat, then the transmissibility of the total structure may be investigated. To insure that the time frame coincided with a shock event, only those shock signatures obtained from the "shock signature" analysis were used for level analysis. The significance of the level analysis is that not all bow impacts are transmitted to the stern and that the distribution of impacts is greater at the stern.

7.1.1 Level Count List

The following program is in FORTRAN-IV and requires 3K words of core for operating. It was developed by Wyle Laboratories to operate on a Sigma-V computer in System RBM-1 with a symbolic and Fortran compiler. Peripheral requirements include:

- 1 - Data tape - 120 double packed 16 bit words/record
- 2 - Scratch tape - program output
- 5 - RAD
- 105 - Card reader
- 108 - Line printer

```
C
C
C   C8MM= 80 CHARACTER C8MMENT 8N START 8F TAPE (20A4)
C    NRUN= RUN NUMBER IDENTIFIER (I3)
C   NHIST= NUMBER 8F (30 SEC) HIST8GRAMS FR8M EACH TRACK
C   SENS= SENSITIVITY IN MV./G
C      TK= DATA TRACK NUMBER (1 8R 2, BUFIN HALF W8RDS)
C   DATA1 AND DATA2 ARE DE-MUX. TRACKS BUFOUT IN 120 W8RD REC8RDS
C
C
C
      DIMENSI8N BUFF1(900),C8MM(20),DATA1(200),DATA2(200)
      DIMENSI8N          DBUFF(120),GLEVCT(80),ALEVCT(80),ABUFF(120)
      INTEGER HIST,TK
      REWIND 1
      REWIND 2
      CALL RADREW(5)
      NST=54000
      NREC=    (NST/120)
      INDEX=0
      TK=2
      KK=0.0
      HIST=1
      NHIST=1
      SENS1=22.5
      SENS2=25.0
      READ(105,1)NRUN
1     F8RMAT(I3)
      READ(1  ,12) C8MM
12    F8RMAT(20A4)
      ISKP=NREC*(HIST-1)+1
      D8 10 I=1, ISKP
      CALL SKPREC
   10 C8NTINUE
      IF(HIST.EQ.NHIST) INDEX=1
      WRITE(108,200)NRUN,TK
      WRITE(108,222) C8MM,NRUN
  200 F8RMAT(1H0,'RUN ',I2,'     TRANSDUCER ',I2)
  222 F8RMAT(T20,20A4,10X,I3)
      DMEAN=0.0
      ADMEAN=0.0
   50 D8 210 IREC=1,NREC
```

```
      CALL BUFIN (1,BUFF1,120)
      CALL STATUS (1,K)
      IF(K.GT.1) CALL SKPREC
      IF(K.GT.1.) KK=KK+1
      IF(K.GT.1) GO TO 210
      J=0
      M=0
      DO  110 I=1,120
      M=M+1
      K =(I-1)*2
S     LW,1      K
S     LH,2      BUFF1,1
S     STW,2     K
S     AI,1      1
S     LH,2      BUFF1,1
S     STW,2     ICT
      DATA1(M)=FLOAT(K)/3.278/SENS1
      DATA2(M)=FLOAT(ICT)/3.2768/SENS2
      ADMEAN=ADMEAN+DATA1(I)
   11 DMEAN=DMEAN+DATA2(I)
  110 CONTINUE
      CALL RADWRT(5,DATA1,120,0,+300,+300)
      CALL RADWRT(5,DATA2,120,0,+300,+300)
  210 CONTINUE
      NREC=NREC-KK
      NST=NREC*120
      DMEAN=DMEAN/FLOAT(NST)
      ADMEAN=ADMEAN/FLOAT(NST)
      CALL RADREW(5)
      AMSL=0.0
      RMSL=0.0
      DO 60 I=1,80
      ALEVCT(I)=0.0
   60 GLEVCT(I)=0.0
      DO 20 IREC=1,NREC
      CALL RADRD(5,ABUFF,120,0,+400,+400)
      CALL RADRD(5,DBUFF,120,0,+400,+400)
      DO 21 I=1,120
      AMSL=AMSL+(ABUFF(I)-ADMEAN)**2
   21 RMSL=RMSL+(DBUFF(I)-DMEAN)**2
   20 CONTINUE
  352 FORMAT (3X,I3)
      AMSL=SQRT(AMSL/(FLOAT(NST-1)))
      RMSL=SQRT(RMSL/(FLOAT(NST-1)))
      AGLEV=AMSL/10
      DGLEV=RMSL/10.
      WRITE(108,250)NST,DMEAN,RMSL,DGLEV
  250 FORMAT(1H0,'NUMBER OF POINTS = ',I6/1H0,'MEAN = ',E15.7,'      RMS L
     1EVEL = ',E15.7/1H0,'LEVEL INCREMENT = ',E15.7)
      NCHAN=2
      WRITE(2,501)NRUN,NCHAN,RMSL,DGLEV,AMSL
  501 FORMAT(2I3,3F4.2)
   24 CONTINUE
```

```
      CALL RADREW(5)
      DØ 30 IREC=1,NREC
      CALL RADRD(5,ABUFF,120,0,+400,+400)
      CALL RADRD(5,DBUFF,120,0,+400,+400)
      DØ 31 I=1,120
      ADAT=(ABUFF(I)-ADMEAN)/AGLEV
      DAT=(DBUFF(I)-DMEAN)/DGLEV
      IF((DGLEV*ABS(DAT)).GT.(4.*RMSL))GØ TØ 32
      IADAT=IFIX(ADAT)
      IDAT=IFIX(DAT)
      IF(IDAT.NE.0)GØ TØ 25
      IF(DAT.EQ.0.)GØ TØ 26
      IF(DAT.LT.0)GLEVCT(40)=GLEVCT(40)+1.
      IF(DAT.GT.0)GLEVCT(41)=GLEVCT(41)+1.
      GØ TØ 27
   26 GLEVCT(40)=GLEVCT(40)+0.5
      GLEVCT(41)=GLEVCT(41)+0.5
      GØ TØ 27
   25 IF(IDAT.GE.0)GLEVCT(41+IDAT)=GLEVCT(41+IDAT)+1.
      IF(IDAT.LT.0)GLEVCT( 40+IDAT)=GLEVCT(40+IDAT)+1.
   27 IF(IADAT.NE.0) GØ TØ 45
      IF(ADAT.EQ.0.) GØ TØ 46
      IF(ADAT.LT.0) ALEVCT(40)=ALEVCT(40)+1.
      IF(ADAT.GT.0)ALEVCT(41)=ALEVCT(41)+1.
      GØ TØ 47
   46 ALEVCT(40)=ALEVCT(40)+0.5
      ALEVCT(41)=ALEVCT(41)+0.5
      GØ TØ 47
   45 IF(IADAT.GE.0)ALEVCT(41+IADAT)=ALEVCT(41+IADAT)+1.
      IF(IADAT.LT.0)ALEVCT(40+IADAT)=ALEVCT(40+IADAT)+1.
   47 GØ TØ 31
   32 IND=IREC*120+I-IREC
  500 FØRMAT(1H0,'PØINT ',I6,' HAS A VALUE ØF ',E15.7)
   31 CØNTINUE
   30 CØNTINUE
      WRITE(108,351) (GLEVCT(I),I=1,80)
      WRITE(108,351) (ALEVCT(I),I=1,80)
  351 FØRMAT(/10(2X,E10.4))
      DØ 600 I=81,160
      J=(I-80)
  600 GLEVCT(I)=ALEVCT(J)
      WRITE(2) (GLEVCT(I),I=1,160)
      IF(INDEX.EQ.1)GØ TØ 999
      GØ TØ 50
  300 WRITE(108,350)
  350 FØRMAT(1H0,'RAD WRITE ERRØR - JØB ABØRTED')
      GØ TØ 50
  400 WRITE(108,450)
  450 FØRMAT(1H0,'RAD WRITE ERRØR - JØB ABØRTED')
      GØ TØ 50
999   REWIND 2
      RETURN
      END
```

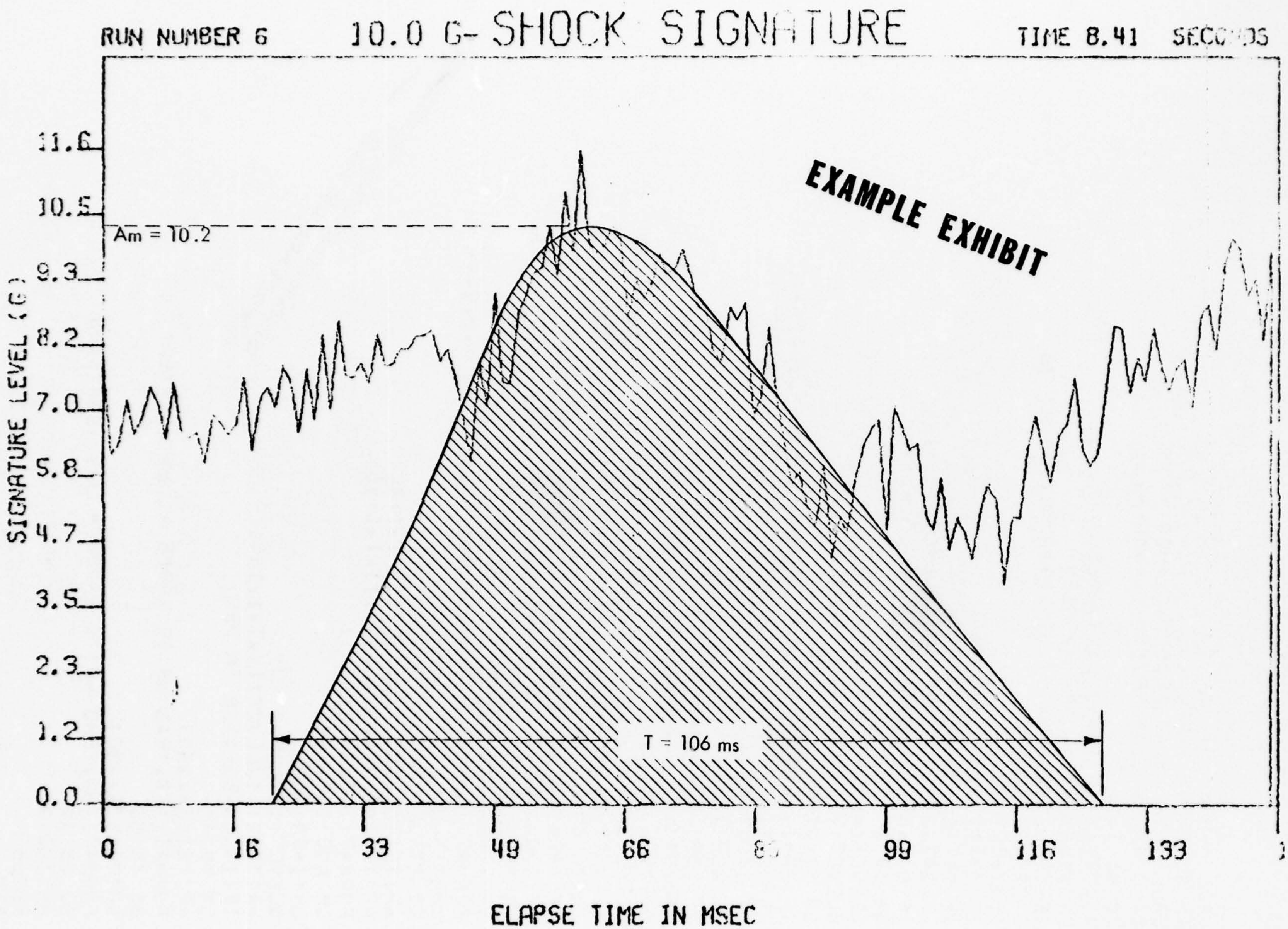


FIGURE IV-24. SIGNATURE REDUCTION EXAMPLE

70% 292-531 100

102

7.2 Shock Signature

Shock signatures were obtained from the acquired data. A threshold of 10 g was chosen to characterize a shock event. This threshold was required to be maintained for three consecutive data points before the shock event was used for analysis. Prior to testing for the threshold, the root mean square (rms) of each data point was determined. Once a given shock event was chosen for analysis, the computer program backed up 60 milliseconds before acquiring the signature to be plotted and then acquired for 150 milliseconds. Since preliminary investigation revealed that most events lasted only about 102 milliseconds, this assured a full signature for most events.

Fundamental kinematics dictates that:

$$E_K = 1/2\ mv^2$$

and

$$v = at$$

where

E_K = kinetic energy

m = mass

v = velocity

a = acceleration

t = time

∴ the kinetic energy of the boat can be approximated to be:

$$E_K = 1/2\ m(at)^2\ .$$

Since Figure IV-24 is a plot of acceleration versus time, the area under any given geometric figure can be related to the kinetic energy of the system by the equation

$$\text{Area} = at = (2E_K M)^{1/2}\ .$$

For the case of a dynamic system, M should be considered the effective mass since the momentum effect has not been considered and the sensor is responding to both skin (vibration) and center of mass (shock) information.

If the signature approximates a rounded triangle as most do, then the area may be estimated to be:

$$\text{Area} = \text{base} \times \text{height} = b \times h$$

where h may be replaced by the amplitude A_m and b may be replaced by the duration T. Since the shock event is superimposed on random vibration noise, the shock event should be projected down to the base line. It must be remembered when making this approximation, that the displayed information is the 1.5 millisecond (2000 samples per second averaged over three samples) rms value of the recorded data, hence everything is displayed in the positive acceleration direction.

Relating the energy to the amplitude time information, we obtain

$$E_K = (A_m T)^2/2M.$$

Since the value of M cannot be established, this equation may be written

$$E_K = K(A_m T)^2$$

where K is a proportionality constant related to the effective mass at the sensor location.

Through additional studies the value of K can be determined for various types of boat construction techniques.

For comparison reasons, only signatures from Runs 3, 4, 6, and 7 were obtained for analysis. These signatures are found in the reduced data (Appendix IV-B) with resulting conclusions found in Section 9.0. The computer program list follows in Section 7.2.1.

7.2.1 Shock Signature List

The following listing is in FORTRAN-IV and requires less than 6K of words of core for operating. It was developed to operate on a Sigma-V computer in System RBM-1 with a symbolic and Fortran compiler. Peripheral requirements include:

- 1 - Data tape - 120 double packed 16 bit words/record
- 2 - Scratch tape - program output
- 105 - Card reader
- 108 - Line printer

```
      DIMENSIØN DATA1(300),DATA2(300),BUFF1(120),BUFF2(120)
      DIMENSIØN BUFF3(1080),BUFF4(1080)
1     FØRMAT(I3,2F10.2)
2     FØRMAT(10F7.2)
3     FØRMAT(1H1,T9,'RUN NUMBER',I3,10X,'DATA TRACK 1-',F6.2,' SECØNDS'1
     10X,'THRESHØLD EQUALS ',F4.1,' G',/)
4     FØRMAT(//,T20,'DATA TRACK2',/)
5     FØRMAT (20A4)
6     FØRMAT  (//,T20,'RETARD TIME = ',F5.2,'MSECØNDS',//)

      REWIND 1
      REWIND 2
      KK=0
      READ(105,1) NRUN,TH,BTIME
      IBK=IFIX(BTIME/.5)
999   READ(1,5) LBL
      CALL SKPREC
      SENS=25.0
      KT=0
      IF( NRUN.EQ.0) GØ TØ 100
      DØ 11 I=1,120
11    BUFF3(I)=0.0
10    DØ 30 J=1,8
      M=0
      CALL BUFIN(1,BUFF1,120)
      CALL STATUS(1,K)
      GØ TØ  (20,100,90) K
20    CØNTINUE
      KT=KT+1
      DØ 30 I=1,120
      M=M+1
      K=(I-1)*2
S     LW,1     K
S     LH,2     BUFF1,1
S     STW,2    K
S     AI,1     1
S     LH,2     BUFF1,1
S     STW,2    ICT
      L=J*120
      BUFF3(L+M)= SQRT ((FLØAT(K)  /3.278/SENS)**2)
      BUFF4(L+M)= SQRT ((FLØAT(ICT)/3.278/SENS)**2)
30    CØNTINUE
      IST=1
      IF(KT.EQ.8) IST=120
      DØ 40 I=IST,780
      IF(BUFF3(I).GE.TH.AND.BUFF3(I-1).GE.TH.AND.BUFF3(I-2).GE.TH)
     1GØ TØ 45
```

```
40      CONTINUE
        DO 41 L=1,120
        BUFF3(L)=BUFF3(780+L)
41      BUFF4(L)=BUFF4(780+L)
        GO TO 10
45      CONTINUE
        KK=KK+1
        TIME=((((KT-8)*120)+I)*.5)/1000
        DO 50 J=1,300
        DATA1(J)=BUFF3(I-IBK)
        DATA2(J)=BUFF4(I-IBK)
50      I=I+1
        WRITE(108,3)NRUN,TIME,TH
        WRITE(108,2)(DATA1(J),J=1,300)
        WRITE(2,1)NRUN,TH,TIME
        WRITE(108,6)  BTIME
        WRITE(2,2) (DATA1(J),J=1,300)
        WRITE(108,4)
        WRITE(108,2)(DATA2(J),J=1,300)
        WRITE(2,2) (DATA2(J),J=1,300)
        GO TO 10
90      CALL SKPREC
        GO TO 10
100     REWIND 1
        REWIND 2
        TH=TH-10
        IF(TH.LE.9)STOP
        GO TO 999
        STOP
        END
```

7.3 Shock

Shock analysis was performed on all runs where an event detected had a value greater than ± 20 g's. Events of ± 40 g's were analyzed for particular runs. The computer software was developed to detect acceleration levels above a threshold value. Once this occurred, it tested digital samples prior to the threshold detection until the absolute value of five consecutive samples were within ± 5 mv. (.2 g's). When this condition was obtained, the software then acquired in the forward time direction for 50 ms. This 50 ms. of reduced data was transferred to computer storage for the performance of various analysis techniques. In most cases, a sufficient number of events for analysis occurred within the first 30 seconds of data for each run. The frequency range for analysis was limited to 5 Hz - 1000 Hz and was analyzed in third octave increments. After analysis, the resulting output was stored on magnetic tape for graphic presentation at a later time.

In reviewing the presented data, one must keep in mind how the analysis was performed. An analogy may be drawn between shock analysis and a steel bar with springs attached. Each spring acts as a filter tuned to a specific 1/3 octave band and permits excitation only at frequencies within the 1/3 octave band. The peak excitation value recorded at the unattached end of each spring when the connecting bar is excited by the shock signature is recorded as the amplitude component in the 1/3 octave band associated with the respective spring.

Upon reviewing the data presented in this text, it is noted that the recorded values for station (6) are much greater than station (5). In order to understand this discrepancy we must consider the mathematic technique to analyzing the system described above.

<u>Definition of Shock Spectrum</u> - The equation of motion of a second-order elastic system (spring-mass-dashpot) in response to an applied force f(t) is

$$\ddot{x} + 2\omega_n \xi x + \omega_n \dot{x} = f(t) \qquad (1)$$

where ω_n is the undamped natural frequency of the system and ξ is the damping ratio. The general solution of (1) is

$$x(t) = \frac{1}{m\omega_d} \int_0^t f(\tau)h(t-\tau)d\tau + g(x_0, \dot{x}_0) \qquad (2)$$

where h(t) is impulse response of the system and m is the mass, ω_d is the damped natural frequency given by

$$\omega_d = \sqrt{\omega_n^{\,2} - (\frac{c}{2m})^2} \qquad \text{(c is damping coefficient).}$$

For a second order system, the impulse response is

$$h(t) = e^{-\xi\omega_n t} \qquad \sin \omega_d t \ . \qquad (3)$$

Thus, if we assume that at t=0, $x_0 = x_0 = 0$, then

$$x(t) = \frac{1}{m\omega_d} \int_0^t f(\tau)\, e^{-\xi \omega_n (t-\tau)} \sin \omega_d (t-\tau) d\tau \, (\phi) \tag{4}$$

A shock spectrum is defined as the maximum amplitude of response of a series of second order systems of varying natural frequencies to a given forcing function f(t). The response may be converted to acceleration by multiplication by ω_d and f(t)/m is a disturbing acceleration; i.e.,

$$\ddot{x}(t) = \omega_d \int \ddot{Z}(\tau)\, e^{-\xi \omega_n (t-\tau)} \sin \omega_d (t-\tau) d\tau \tag{5}$$

and the shock spectrum is a representation of $|\ddot{x}(t)|_{max}$ for a range of ω_d.

<u>Application to Reported Data</u> - Examination of Figures B-12 through B-55 shows that acceleration measurements at the measuring positions are composed of a dc offset (or a low frequency) of typically 7g on which is superimposed higher frequency components, i.e., $\ddot{Z}(t)$ may be represented by:

$$\ddot{Z}(t) = K + \ddot{Z}_1(t) \tag{6}$$

where K is the constant offset and $\ddot{Z}_1(t)$ is approximately of zero mean. Making the assumption that $\xi=0$ (in which case $\omega_d = \omega_n$) substitution into equation (5) and integrating gives

$$\ddot{x}(t) = K(1-\cos\omega_n t) + \int_0^t \omega_n \ddot{Z}_1(t) \sin(\omega_n - \tau) d\tau$$

which shows that the contribution to the shock spectrum of a dc offset in the data has a maximum of twice the offset.

Figures B-56 through B-83 contain the shock spectra based on the time series (some of which are) contained in Figures B-12 through B-55. Station (5) data are represented by spectra which range from 0.5g at low frequency to approximately 70g at higher frequencies. For $\ddot{Z}(t)$ which has peaks in the range 10-20g this is not unreasonable; it shows resonant second order systems with reasonable dynamic magnification factors (Q values) of up to 10.

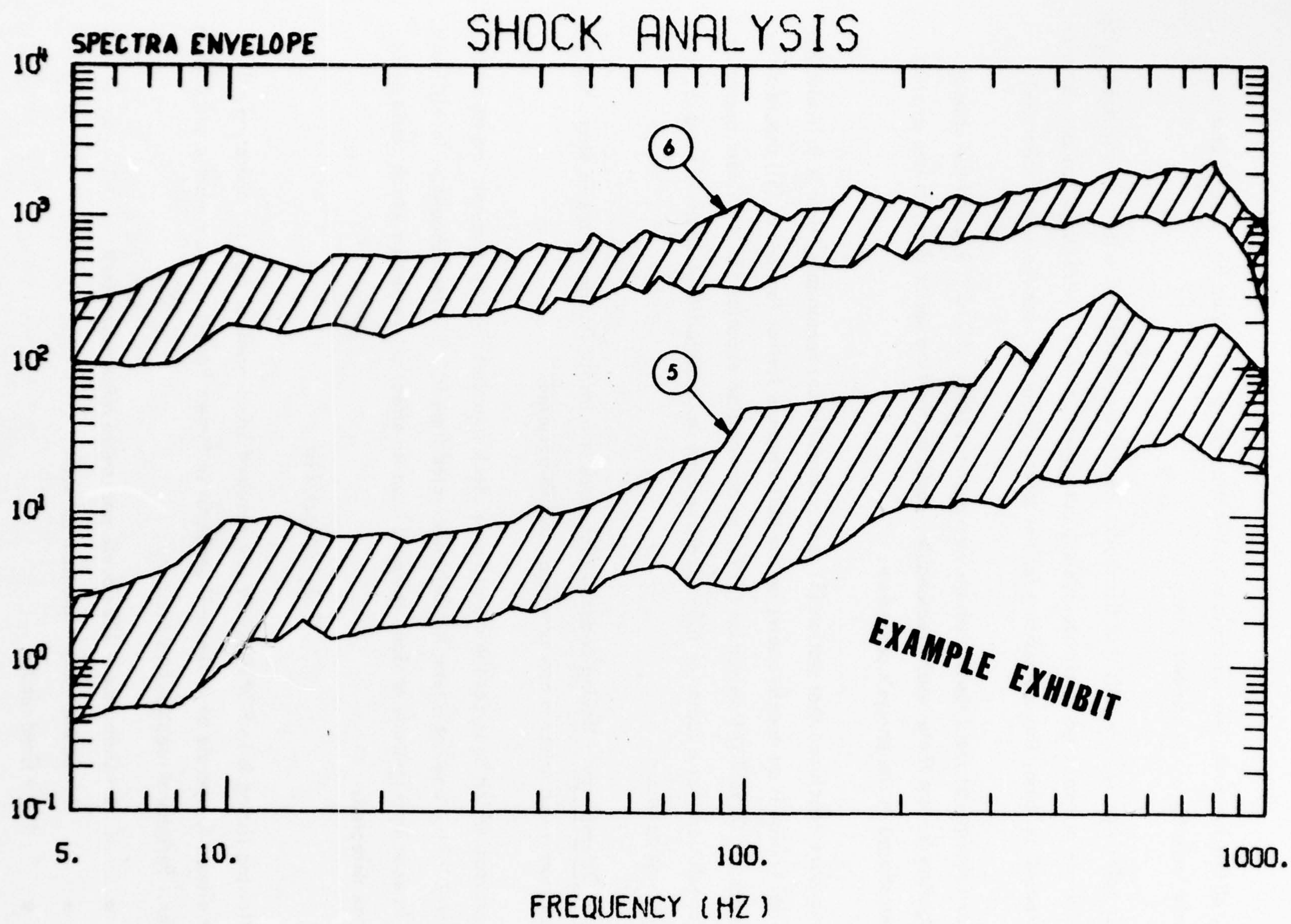


FIGURE IV-25. SHOCK ANALYSIS ENVELOPES

90%

292-531 (107)

102

(Note, at this juncture, that dynamic magnification factor is defined by $Q = \frac{1}{2\xi}$ and is obviously large for a low damped system.)

Another point worthy of note is that the shocks are not clearly defined with a steady decay after an initial one or two large amplitude cycles, but appear to have a wide-band random vibration superimposed on them, thus accounting for the spread of energy over the whole spectrum.

Data from station (6) yield spectra which vary over the range 100 to 1000g and the crux of investigation is: are these results reasonable, based on the time series data, or has an error been introduced in the analysis procedure.

Since we have concluded that station (5) data and results are reasonable, then is it likely that station (6) (which is an accelerometer on the hull structure further forward of (5)) should differ by a factor of 100 to 200 from station (5)? The convolution equation (5) is a linear operation, so the conclusion that a factor of 100-200 of the time series data from stations (5) and (6) is unlikely must be drawn.

Source of Discrepancy - Having deduced that shock spectra for station (6) are in error, the next question which arises is how or where has this occurred.

In the program which analyzes the data to give shock spectrum the two channels are treated differently in that one has a term XMEAN subtracted from it. This term should be in millivolts. If it is in error in magnitude or sign, it would have an effect on the results which could be in the range detected.

7.3.1 Shock List

The following listing is in FORTRAN-IV and required 8K of words of core for operating. It was developed to operate on a Sigma-V computer in System RBM-1 with a symbolic and Fortran compiler. Peripheral requirements include:

- 1 - Data tape - 120 double packed 16 bit words/record
- 2 - Scratch tape - program output
- 105 - Card reader
- 108 - Line printer.

```
      COMMON BUFF1(120),BUFF3(260),BUFF2(1080)
      COMMON BUFF5(260),BUFF4(1080)
      DIMENSION LBL(20) ,FRQ(200),SHK(200),THK(200)
      SRATE = 2000.
      DT = 1./SRATE
      READ (105,900) NRUN,NCHAN,SENS,THRESH,XMEAN,OCT,FL,FU
  900 FORMAT (A4,I6, 7F10.0)
      FINC = 2.**(1./OCT)
      FRQ(1) = FL
      KK = 1
    5 KK = KK+1
      FRQ(KK) = FINC*FRQ(KK-1)
      IF (KK.GE.200)GO TO 8
      IF (FRQ(KK).LT.FU)GO TO 5
    7 FRQ(KK) = FU
    8 CONTINUE
      WRITE (108,960) (FRQ(I),I=1,KK)
  960 FORMAT (5X 10F10.3)
      DMPNG = .01
      REWIND 1
      REWIND 2
      READ (1,910) LBL
  910 FORMAT (20A4)
  920 FORMAT (10X 20A4)
      WRITE (108,920) LBL
      CALL SKPREC
      KCHAN = NCHAN-1
      NCHAN=-1
      IF(KCHAN.EQ.0) NCHAN=1
      IB2 = 0
      DO 10 I=1,3
   15 CALL BUFIN(1,BUFF1,120)
      CALL STATUS(1,K)
      IF(K.GT.1) CALL SKPREC
      IF(K.GT.1) GO TO 10
      DO 10 J=1,120
      K = 2*(J-1)+KCHAN
S     LW,1     K
S     LH,2     BUFF1,1
S     STW,2    K
      IB2 = IB2+1
      BUFF3(IB2) = (FLOAT(K)/3.2768-XMEAN)/SENS
      K=K+NCHAN
S     LW,1     K
S     LH,2     BUFF1,1
S     STW,2    K
      BUFF5(IB2)=FLOAT(K)/3.2768/SENS
   10 CONTINUE
      KTIME = 0
      NDOF = 0
   20 CONTINUE
      IB2 = 0
      CALL RELOAD(IB2,KTIME,KCHAN,NCHAN,SENS,XMEAN)
```

```
      DO 30 I=1,1080
      IF (ABS(BUFF2(I)).GE.THRESH)GO TO 50
   30 CONTINUE
      NDOF = NDOF+2
   35 DO 40 I=1,260
      BUFF5(I)=BUFF4(I+820)
   40 BUFF3(I) = BUFF2(I+820)
      GO TO 20
   50 CONTINUE
      NDOF = 0
      I = I-20
      JJ = I
   55 A = 1.1*ABS(BUFF2(I))
      X1 = ABS(BUFF2(I-1))
      X2 = ABS(BUFF2(I-2))
      X3 = ABS(BUFF2(I-3))
      X4 = ABS(BUFF2(I-3))
      X5 = ABS(BUFF2(I-5))
      IF (X1.LE.A .AND. X2.LE.A .AND. X3.LE.A .AND. X4.LE.A
     1    .AND. X5.LE.A)GO TO 60
      I = I-1
      IF (I.GT.-260)GO TO 55
   60 CONTINUE
C
      J = I+400
      IF (J.LE.1080)GO TO 70
      L = 1
      DO 80 K=I,1080
      BUFF2(L) = BUFF2(K)
      BUFF4(L)=BUFF4(K)
   80 L = L+1
      CALL RELOAD(L,KTIME,KCHAN,NCHAN,SENS,XMEAN)
      I = 1
      J = 400
   70 TIME = .06*FLOAT(KTIME)-.0005*FLOAT(1080-I)
      WRITE (108,940) THRESH, TIME, JJ, I
  940 FORMAT (/ 10X F10.3, '  ', 5X F10.3, ' SECS', 2I10)
  950 FORMAT (/13F 10.3)
C    SHOCK SPECTRUM CALCULATION
      CALL SHOCK(SRATE,400,BUFF2(I),FRQ,SHK,KK,DMPNG)
      CALL SHOCK(SRATE,400,BUFF4(I),FRQ,THK,KK,DMPNG)
      WRITE (2) SRATE,KK,DMPNG,I,JJ,TIME,THRESH,NRUN
      WRITE (2) (FRQ(I), I=1,KK)
      WRITE (2) (SHK(I),I=1,KK)
      WRITE (2) SRATE,KK,DMPNG,I,JJ,TIME,THRESH,NRUN
      WRITE (2) (FRQ(I), I=1,KK)
      WRITE(2) (THK(I),I=1,KK)
      GO TO 35
      END
```

```
      SUBROUTINE RELOAD(IB2,KTIME,KCHAN,NCHAN,SENS,XMEAN)
      COMMON BUFF1(120),BUFF3(260),BUFF2(1080)
      COMMON BUFF5(260),BUFF4(1080)
   10 CALL BUFIN(1,BUFF1,120)
      CALL STATUS(1,K)
      GO TO(20,50,60)K
   20 KTIME = KTIME+1
      DO 30 J=1,120
      K = 2*(J-1)+KCHAN
S     LW,1     K
S     LH,2     BUFF1,1
S     STW,2    K
      IB2 = IB2+1
      BUFF2(IB2) = (FLOAT(K)/3.2768-XMEAN)/SENS
      K=K+NCHAN
S     LW,1     K
S     LH,2     BUFF1,1
S     STW,2    K
      BUFF4(IB2)=FLOAT(K)/3.2768/SENS
      IF (IB2.EQ.1080)GO TO 40
   30 CONTINUE
      GO TO 10
   40 IB2 = 0
      RETURN
   50 ENDFILE 2
      REWIND 1
      REWIND 2
      STOP
   60 CALL SKPREC
      GO TO 10
      END
```



```
      SUBROUTINE SHOCK(DT,NS,RF,HI,SI,NF,ZT)
      DIMENSION RF(1),HI(1),SI(1)
      DATA PI/3.1415927/
      RZ=SQRT(1.0-ZT*ZT)
      TH=ATAN(ZT/RZ)
      DO 90 I=1,NF
      FREQ=2.0*PI*HI(I)
      FRDT=FREQ/DT
      RZOT=RZ*FRDT
      EZ=EXP(-ZT*FRDT)/RZ
      CA=EZ*COS(RZOT-TH)
      CB=EZ*SIN(RZOT)
      CC=1.0-CA
      CD=EZ*COS(RZOT+TH)
      CE=-CC/FRDT
      CF=1.0-CB/FRDT+2.0*ZT*CE
```

```
C
C     PRIMARY SHOCK RESPONSE
C
      PR=0.0
      XO=0.0
      VO=0.0
      ACL1=0.0
   41 NX=NS
      IF(NX.GT.NS)NX=NS
      NY=1
   42 DO 85 K=1,NX,NY
      ACL2=RF(K)
      AS=ACL2-ACL1
      AO=ACL1+XO
      XO=CA*XO+CB*VO-CC*ACL1
      XO=XO-CF*AS
      VO=CD*VO-CB*AO
      VO=VO+CE*AS
      ACL1=ACL2
      AO=-XO-2.0*ZT*VO
      ABX=ABS(AO)
      IF(ABX-PR)85,85,84
   84 PR=ABX
   85 CONTINUE


C
C     RESIDUAL SHOCK RESPONSE
C
      VO=(VO+ZT*XO)/RZ
      AO=SQRT(XO*XO+VO*VO)
      IF(AO-PR)86,86,1
    1 IF(ZT)15,15,2
    2 IF(XO)4,3,4
    3 PH=PI
      GO TO 10
    4 IF(VO/XO)5,6,7
    5 PH=ATAN(-XO/VO)
      PH=PI-PH
      GO TO 10
    6 PH=PI/2.0
      GO TO 10
    7 PH=ATAN(XO/VO)
   10 PH=PH+TH+TH
   11 WT=PI-PH
   12 IF(WT)13,14,14
   13 WT=WT+PI
      GO TO 12
   14 WT=-WT*ZT/RZ
      AO=AO*EXP(WT)
      IF(AO-PR)86,86,15
   15 PR=AO
   86 CONTINUE
   90 SI(I)=PR
   99 RETURN
      END
```

7.4 Power Spectral Density

PSD analysis was performed on several runs where data was acquired. A lower limit of 6000 data points was set to insure a good data sample.

The program allows 50 degrees of freedom at a frequency increment of 3.9 Hz. The frequency range is from 3.9 Hz to 994.5 Hz. Program output is stored on magnetic tape for presentation at a later time.

As with shock spectrum analysis, an analogy may be drawn to a mechanical system. However, in this case we must visualize the distribution of mean power into 25 frequency bands (two degrees of freedom associated with each band), and since these bands are constant width, we must look only at stationary data.

Extreme caution should be used when considering the PSD information presented. The application of PSD technique for data analysis is used primarily for stationary data of which the analyzed data is not. This technique was utilized only for the purpose of reviewing the data for any unique characteristics.

7.4.1 PSD List

The following listing is in FORTRAN-IV and requires 8K of words for operating. It was developed to operate on a Sigma-V computer in System RBM-1 with a symbolic and Fortran compiler. Peripheral requirements include:

- 1 - Data tape - 120 double packed 16 bit words/record
- 2 - Scratch tape - program output
- 105 - Card reader
- 108 - Line printer

```
      DIMENSION LBL(20) ,FRQ(512),SHK(512),THK(512)
      COMMON BUFF1(120),BUFF3(260),BUFF2(1080)
      COMMON BUFF5(260),BUFF4(1080)
      SRATE = 2000.
      DT = 1./SRATE
      READ (105,900) NRUN,NCHAN,SENS,THRFSH,XMEAN
900   FORMAT (A4, I6, 7F10.0)
```

```
      M = 9
      N = 2**M
      H = FLBAT(N)
      DF=SRATE/H
      FRQ(1) =DF
      DB 5 KK=2,512
    5 FRQ(KK) = FRQ(KK-1)+DF
      DB 8 I=1,512
      SHK(I) = 0.
      THK(I) = 0.
    8 CBNTINUE
      XMEAN2=0.
      RMS2=0.
      XMEAN4=0.
      RMS4=0.
      WRITE (108,960) (FRQ(I),I=1,N)
  960 FBRMAT (5X 10F10.3)
      REWIND 1
      REWIND 2
      READ (1,910) LBL
      CALL SKPREC
  910 FBRMAT (20A4)
  920 FBRMAT (10X 20A4)
      WRITE (108,920) LBL
      CALL SKPREC
      KCHAN = NCHAN-1
      NCHAN=-1
      IF(KCHAN.EQ.0) NCHAN=1
      IB2 = 0
      DB 10 I=1,3
   15 CALL BUFIN(1,BUFF1,120)
      CALL STATUS(1,K)
      IF(K.GT.1) CALL SKPREC
      IF(K.GT.1) GB TB 10
      DB 10 J=1,120
      K = 2*(J-1)+KCHAN
S     LW,1     K
S     LH,2     BUFF1,1
S     STW,2    K
      IB2 = IB2+1
      BUFF3(IB2) =  FLBAT(K)/3.2768/SENS
      K=K+NCHAN
S     LW,1     K
S     LH,2     BUFF1,1
S     STW,2    K
      BUFF5(IB2)=FLBAT(K)/3.2768/SENS
   10 CBNTINUE
      KTIME = 0
      NDBF = 0
   20 CBNTINUE
      IB2 = 0
      CALL RELBAD(IB2,KTIME,KCHAN,NCHAN,SENS,XMEAN)
```

```
      DO 30 I=1,1080
      IF (ABS(BUFF2(I)).GE.THRESH)GO TO 50
30    CONTINUE
      CALL TD(BUFF2,RMS2,XMEAN2,N)
      CALL TD(BUFF4,RMS4,XMEAN4,N)
      CALL TD(BUFF2(N+1),RMS2,XMNAN2,M)
      CALL TD(BUFF4(N+1),RMS4,XMEAN4,N)
      CALL FFTCSS(M,BUFF2,0)
      CALL FFTCSS(M,BUFF4,0)
      CALL PRSL DY (BUFF2,SHK,N)
      CALL PRSL DY (BUFF4,THK,N)
      CALL FFTCSS(M,BUFF2(N+1),0)
      CALL FFTCSS(M,BUFF4(N+1),0)
      CALL PRSLDY(BUFF2(N+1),SHK,N)
      CALL PRSLDY(BUFF4(N+1),THK,N)
      NDOF = NDOF+4
35    DO 40 I=1,260
      BUFF5(I)=BUFF4(I+820)
40    BUFF3(I) = BUFF2(I+820)
      IF(NDOF.LT.50.) GO TO 20
      T1 = FLOAT(NDOF*256)
      XMEAN2 = XMEAN2/T1
      XMEAN4 = XMEAN4/T1
      RMS2 = SQRT(RMS2/T1-XMEAN2*XMEAN2)
      RMS4 = SQRT(RMS4/T1-XMEAN4*XMEAN4)
      PSDRMS2 = 0.
      PSDRMS4 = 0.
      DO 70 I=2,256
      T1 = FRQ(I)-FRQ(I-1)
      PSDRMS2 = PSDRMS2+.5*(SHK(I)+SHK(I-1))*T1
      PSDRMS4 = PSDRMS4+.5*(THK(I)+THK(I-1))*T1
70    CONTINUE
      WRITE(108,961)(SHK(I),I=1,20)
      WRITE (108,961) (THK(I),I=1,20)
961   FORMAT(20E13.5)
      T1 = RMS2/PSDRMS2
      T2 = RMS4/PSDRMS4
      DO 80 I=1,256
      SHK(I) = SHK(I)*T1
80    THK(I) = THK(I)*T2
      WRITE (2) KTIME,NDOF,NRUN,THRESH
      WRITE (2) FRQ
      WRITE (2) SHK
      WRITE (2) THK
50    NDOF=0
      DO 17 I=1,512
      SHK(I)=0.
17    THK(I)=0.
      XMEAN2=0.
      RMS2=0.
      XMEAN4=0.
      RMS4=0.
      GO TO 20
940   FORMAT (/ 10X F10.3, '  ', 5X F10.3, ' SECS', 2I10)
950   FORMAT (/13F 10.3)
      END
```

```
      SUBRØUTINE RELBAD(IB2,KTIME,KCHAN,NCHAN,SENS,XMEAN)
      CØMMØN BUFF1(120),BUFF3(260),BUFF2(1080)
      CØMMØN BUFF5(260),BUFF4(1080)
   10 CALL BUFIN(1,BUFF1,120)
      CALL STATUS(1,K)
      GØ TØ(20,50,60)K
   20 KTIME = KTIME+1
      DØ 30 J=1,120
      K = 2*(J-1)+KCHAN
S     LW,1      K
S     LH,2      BUFF1,1
S     STW,2     K
      IB2 = IB2+1
      BUFF2(IB2) =  FLØAT(K)/3.2768/SENS
      K=K+NCHAN
S     LW,1      K
S     LH,2      BUFF1,1
S     STW,2     K
      BUFF4(IB2)=FLØAT(K)/3.2768/SENS
      IF (IB2.EQ.1080)GØ TØ 40
   30 CØNTINUE
      GØ TØ 10
   40 IB2 = 0
      RETURN
   50 ENDFILE 2
      REWIND 1
      REWIND 2
      STØP
   60 CALL SKPREC
      GØ TØ 10
      END


      SUBRØUTINE PRSLDY(REAL,PSD,M)
      DIMENSIØN PSD(1),REAL(1)
      I = M/2-2
      A = REAL(2)
      REAL(1) = 0.
      REAL(2) = 0.
      DØ 10 J=1,I
      INDR = 2*(J-1)+3
      INDI = INDR+1
      AVR = .5*(REAL(INDR)-.5*(REAL(INDR+2)+REAL(INDR-2)))
      AVI = .5*(REAL(INDI)-.5*(REAL(INDI+2)+REAL(INDI-2)))
   10 PSD(J) = PSD(J)+AVR*AVR+AVI*AVI
      AVR = .5*(REAL(INDR+2)-.5*(REAL(INDR)+A))
      AVI = .5*(REAL(INDI+2)-.5*(REAL(INDI)))
      PSD(I+1) = PSD(I+1)+AVR*AVR+AVI*AVI
      AVR = .5*(REAL(INDR+2)-A)
      AVI = .5*(REAL(INDI))
      PSD(I+2) = PSD(I+2)+AVR*AVR+AVI*AVI
      RETURN
      END
```

```
      SUBROUTINE TD(REAL,RMS,XMN,M)
      DIMENSION REAL(M)
      DO 10 J=1,M
      XMN = XMN+REAL(J)
   10 RMS = RMS+REAL(J)*REAL(J)
      RETURN
      END

      SUBROUTINE FFTCSS(N,REAL,INOUT)
      DIMENSION REAL(1)
      INTEGER OLP,FSTEP,FSEPR,FBSIZ,FDK,FK,FBSIZ1
      NPR = N-1
      FBSIZ = 2**NPR
      IF (INOUT.EQ.0)GO TO 150
      R1 = REAL(1)+REAL(2)
      Q1 = REAL(1)-REAL(2)
      REAL(1) = R1
      REAL(2) = Q1
      FDK = 4096/FBSIZ
      FK = 0
      OLP = FBSIZ-2
      DO 160 MLP=2,OLP,2
      ILP = MLP+1
      FK = FK+FDK
      IF (FK.GT.2048)GO TO 170
      COSN = W(FK+1)
      SINN = W(2049-FK)
      GO TO 180
  170 COSN = -W(4097-FK)
      SINN = W(FK-2047)
  180 INDEX = 2*FBSIZ-ILP+2
      R1 = REAL(ILP)+REAL(INDEX)
      Q2 = REAL(ILP)-REAL(INDEX)
      Q1 = REAL(ILP+1)-REAL(INDEX+1)
      R2 = -REAL(ILP+1)-REAL(INDEX+1)
      T1 = R2*COSN-Q2*SINN
      REAL(ILP) = R1+T1
      REAL(INDEX) = R1-T1
      T1 = R2*SINN+Q2*COSN
      REAL(ILP+1) = Q1+T1
  160 REAL(INDEX+1) = T1-Q1
      ILP = FBSIZ+2
      REAL(ILP) = -(REAL(ILP)+REAL(ILP))
      REAL(ILP-1) = REAL(ILP-1)*2.
  150 CONTINUE
      FSTEP = FBSIZ-1
      ILP = 2**(32-NPR)
      DO 10 MLP=1,FSTEP
      ISW = 1
      FK = 0
      FDK = MLP*ILP
```

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

```
      DO 20 INDEX=1,NPR
      IF (FDK.LT.0)FK=FK+ISW
      ISW = 2*ISW
   20 FDK = 2*FDK
      IF (FK.LE.MLP)GO TO 10
      I1 = 2*FK+1
      I2 = 2*MLP+1
      R1 = REAL(I1)
      Q1 = REAL(I1+1)
      REAL(I1) = REAL(I2)
      REAL(I1+1) = REAL(I2+1)
      REAL(I2) = R1
      REAL(I2+1) = Q1
   10 CONTINUE
      FSTEP = 2
      FDK = 2**13
      FBSIZ1 = 2*FBSIZ+1
   30 FSEPR = FSTEP
      FSTEP = 2*FSTEP
      FDK = FDK/2
      FK = 0
      ISW = 1
      MLP = 0
  120 ILP = MLP+1
   80 CONTINUE
      INDEX = ILP+FSEPR
      GO TO(60,70,50)ISW
   50 R1 = REAL(INDEX)
      Q1 = REAL(INDEX+1)
      REAL(INDEX) = R1*COSN+Q1*SINN
      REAL(INDEX+1) = Q1*COSN-R1*SINN
   60 R1 = REAL(ILP)+REAL(INDEX)
      Q1 = REAL(ILP+1)+REAL(INDEX+1)
      R2 = REAL(ILP)-REAL(INDEX)
      Q2 = REAL(ILP+1)-REAL(INDEX+1)
      REAL(ILP) = R1
      REAL(INDEX) = R2
      REAL(ILP+1) = Q1
      REAL(INDEX+1) = Q2
      GO TO 90
   70 IF (INOUT.NE.0)GO TO 75
      R1 = REAL(ILP)+REAL(INDEX+1)
      R2 = REAL(ILP)-REAL(INDEX+1)
      Q1 = REAL(ILP+1)-REAL(INDEX)
      Q2 = REAL(ILP+1)+REAL(INDEX)
      REAL(ILP) = R1
      REAL(ILP+1) = Q1
      REAL(INDEX) = R2
      REAL(INDEX+1) = Q2
      GO TO 90
```

```
75    R1 = REAL(ILP)-REAL(INDEX+1)
      R2 = REAL(ILP)+REAL(INDEX+1)
      Q1 = REAL(ILP+1)+REAL(INDEX)
      Q2 = REAL(ILP+1)-REAL(INDEX)
      REAL(ILP) = R1
      REAL(ILP+1) = Q1
      REAL(INDEX) = R2
      REAL(INDEX+1) = Q2
90    ILP = ILP+FSTEP
      IF (ILP.LE.(FBSIZ1-FSEPR))GØ TØ 80
      MLP = MLP+2
      IF (MLP.GE.FSEPR)GØ TØ 100
      FK = FK+FDK
      IF (FK.NE.2048)GØ TØ 40
      ISW = 2
      GØ TØ 120
40    ISW = 3
      IF (FK.GT.2048)GØ TØ 95
      CØSN = W(FK+1)
      SINN = W(2049-FK)
      IF (INØUT.NE.0)SINN=-SINN
      GØ TØ 120
95    CØSN = -W(4097-FK)
      SINN = W(FK-2047)
      IF (INØUT.NE.0)SINN=-SINN
      GØ TØ 120
100   IF (FSTEP.LT.FBSIZ1-1)GØ TØ 30
      IF (INØUT.NE.0)RETURN
      FDK = FDK/2
      FK = 0
      R1 = REAL(2)+REAL(1)
      Q1 = REAL(1)-REAL(2)
      REAL(1) = R1+R1
      REAL(2) = Q1+Q1
      ØLP = FBSIZ-2
      DØ 110 MLP=2,ØLP,2
      ILP = MLP+1
      FK = FK+FDK
      IF (FK.GT.2048)GØ TØ 130
      CØSN = -W(FK+1)
      SINN = W(2049-FK)
      GØ TØ 140
130   CØSN = W(4097-FK)
      SINN = W(FK-2047)
140   INDEX = 2*FBSIZ-ILP+2
      R1 = REAL(ILP)+REAL(INDEX)
      Q2 = REAL(ILP)-REAL(INDEX)
      Q1 = REAL(ILP+1)-REAL(INDEX+1)
      R2 = -REAL(ILP+1)-REAL(INDEX+1)
```

```
      T1 = R2*COSN-Q2*SINN
      REAL(ILP) = R1+T1
      REAL(INDEX) = R1-T1
      T1 = R2*SINN+Q2*COSN
      REAL(ILP+1) = Q1+T1
110   REAL(INDEX+1) = T1-Q1
      ILP = FOSIZ+2
      REAL(ILP) = -(REAL(ILP)+REAL(ILP))
      REAL(ILP-1) = 2.*REAL(ILP-1)
200   NPR = FOSIZ*2
      R1 = FLOAT(NPR)*2.
      DO 210 ILP=1,NPR
210   REAL(ILP) = REAL(ILP)/R1
      RETURN
      END


      FUNCTION W(K)
      IF (K.EQ.1)GO TO 10
      IF (K.EQ.2049)GO TO 20
      X = 3.141593/4096.
      W = COS(FLOAT(K-1)*X)
      RETURN
 10   W = 1.
      RETURN
 20   W = 0.
      RETURN
      END
```

8.0 RESULTS

The reduced data (data sheets) from all four types of analyses is presented in Appendix IV-B (Reduced Data for 1975) of this report. They are grouped according to type of analysis and may be identified by the title information at the top of each graph. Not all types of analysis were appropriate to each run, thus will not be found for each.

9.0 CONCLUSIONS

Conclusions drawn from these results will be grouped according to information obtainable from each type analysis. Due to the lack of data from several different type boats for different water conditions, these conclusions are limited in their scope. When considering these conclusions, one should recall that the data analyzed was obtained for structural members and does not include C-M accelerations.

9.1 Level Analysis

The results from level analysis was restricted to low level events (less than four times the RMS value). Runs numbered 1, 3, 4, 6, and 7 support the expected conclusion that:

- The RMS level of induced impact increases with speed.

Runs numbered 3, 4, and 6 support the conclusion that:

- The number of impacts increase from point to point along the center line starting from the stern.

In these cases:

Run 3	31.8%	Bow/Stern	High Speed
Run 4	31.3%	Midship/Stern	High Speed
Run 6	36.0%	Bow/Stern	Low Speed

Since the difference in impact counts may be attributed to damping due to the water, one would expect more damping at low speeds.

Runs numbered 2 and 8 support the conclusion that:

- Low level random vibration occurs on surfaces normal to the water.

This conclusion should be considered with the understanding that center of mass accelerations are not being considered.

9.2 Signature Analysis

Shock signature analysis agrees quite well with the results obtained from previous work. Namely that:

- Range of average duration for shock events is 136 to 168 milliseconds; 160 to 200 milliseconds for a previous boat of slightly longer length (21 as opposed to 17).
- Very few shock events occur above 12 g; 11 g from previous data.
- E_e/K value of 602 to 690 g x millisecond; 400 to 800 g x millisecond reported previously.

These values were obtained under boating conditions that would be considered representative of most recreational boating conditions.

9.3 Shock Analysis

Information obtained from shock analysis was not very conclusive. Spectra for all events appeared to fall off around 800 to 900 Hz. Since this was near the edge of the frequency band for analysis, significance should not be attributed to it without further investigation.

Results from each run show a spectra envelope similar to Figure IV-25. It is expected that a difference in spectra from different boats should be seen, but this conclusion can be drawn only with more data. The spectra for the same run (3) of different magnitude (20 g's vs. 40 g's) supports the conclusion that:

- Shock spectra for a particular boat is independent of the magnitude of impact for large impact values.
- Acceleration on the structural members of a boat may well exceed 40 g's.

Further analysis of similar data for different boats could possibly reveal resonant frequencies for boats leading to information on attenuation coefficients as a function of boat structure.

Discrepancies discussed in Section 7.3 could possibly be corrected but would require considerable further investigation that may not be justifiable in terms of conclusive results. Significance should not be attributed to the reported results from shock analysis of station (6).

9.4 PSD Analysis

Power spectral density analysis on stationary data for the most part indicated broad band random data. Peaks were found at frequencies corresponding to the fundamental first and second resonance of prop pulses (see Runs 1 and 3). These frequencies were shifted down as expected at lower engine speed settings. The low frequency peaks of runs numbered 3 and 8 are attributed to the center of mass motion of the boat.

9.5 Conclusion Summary

- RMS level of induced impact increases with boat speed.
- Number of impacts increase toward the front of the boat.
- Low level random vibration occurs on surfaces normal to the water.
- Most impacts are of less than 12 g under normal recreational boating circumstances.
- Most impacts last for a duration of approximately 100 milliseconds.
- Most values of energy divided by effective mass are on the order of 400 to 800 g millisecond.
- Shock spectra for a particular boat is independent of impact magnitude for large impacts.
- Accelerations on structure members may well exceed 40 g.
- Only dominate frequencies of low level vibration in boat structures are induced by the prop.

10.0 RECOMMENDATIONS

Preliminary results of this investigation indicate a vast need for more data. The format for data acquisition/analysis and presentation is contained herein. Specific recommendations are listed below:

- Concentrate on signature analysis type presentation for clarity and understanding.
- Data from different type environments for existing boats.
- Strain gage data from existing instrumented boats.
- Develop strain gage analysis format.
- Expand temperature data base.
- Instrument several different type boats.
- Conclusive survey of most popular type boats.

Section VI presents a proposed approach in the form of a cost effective methodology for acquiring interpolating induced environmental data.

REFERENCES

1. Losey, R., et al. "Small Boat Subsystems Environment: Preliminary Results of Environment Review." Wyle Laboratories for the U.S. Coast Guard. Contract No. DOT-CG-40672-A. July 1975. (Unpublished)

SECTION V –
PRESENTLY AVAILABLE ACOUSTIC ENVIRONMENTAL DATA

1.0 INTRODUCTION

Reported herein are data and analysis obtained through a literature search of available acoustic data. Data obtained by Wyle Laboratories through their collision research program (Reference 1) is also included.

2.0 ACOUSTIC DATA

As part of collision research, Wyle analyzed data on other noise studies, including studies that measured only water-induced boat noise, and a study that measured air noise inside the human ear at various wind speeds. Wyle also measured the noise level of a group of boats that were not represented in the available data base, including cabin cruisers and "hot rod" boats.

2.1 Sound Levels – Boats

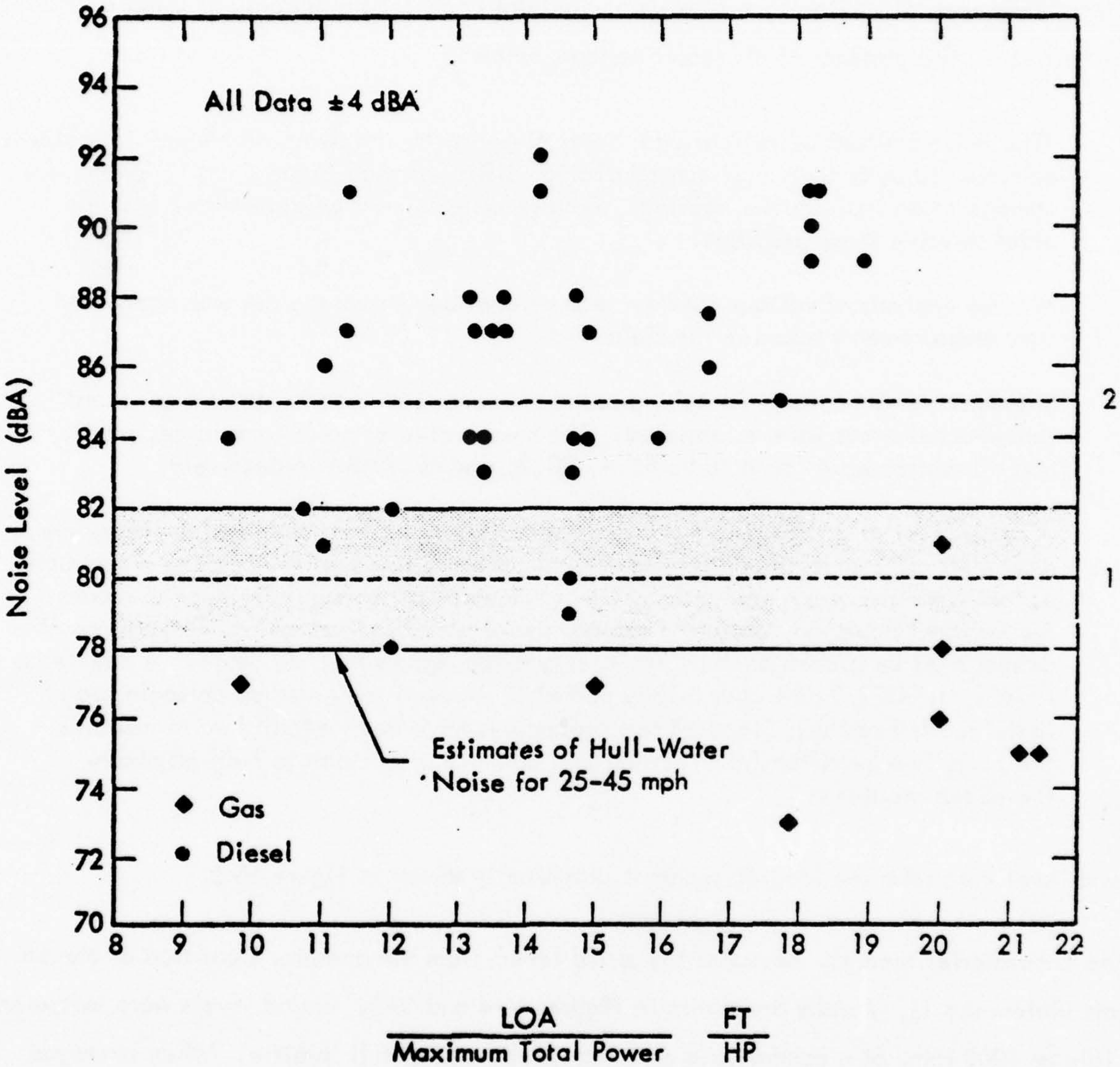
A major outboard motor manufacturing company measured the sound levels of their 1972, 1973, and 1974 motors on three different boats (Reference 2). The results of their study are presented in Figure V-1.

In 1973, Wyle Laboratories conducted a cost-effectiveness study for noise reduction of motorboats for the Environmental Protection Agency (Reference 3). In this study, the sound levels of many boats were measured from a distance of 50 ft (15.2 m) per SAE J-34. While this data could have been used to project the on board noise, it was not done because the projection would not truly represent the sound level received by a passenger in the boat. The passenger receives a noise mix composed of three noise components: wind noise, machinery noise, and water noise. The sound levels measured at 50 ft (15.2 m) will only consist of machinery noise and water noise. Any projection of this noise to reflect the on-board level would be distorted due to the lack of the wind noise component. Some sound measurements, however, were made on the after-cockpits of inboard motorboats and are shown in Figure V-2.

BOAT	HP	RPM	SOUND LEVEL AT OPERATOR'S EAR		COMMENTS
			1974 Eng	1973/2 Eng	
14' Aluminum	2	4200	86.5	92.0	Measured 3' from engine
14' Aluminum	4	4700	85.0	86.5	Measured 3' from engine
14' Aluminum	6	4200	85.0	84.5	Measured 3' from engine
14' Aluminum	9.9	5100	86.5	93.0	Measured 3' from engine
14' Aluminum	15	6000	94.0	93.0	Measured 3' from engine
15' Fiberglass	25	5400	83.5	87.5	Measured 7' from engine
15' Fiberglass	40	4600	90.5	92.0	Measured 7' from engine
15' Fiberglass	50	5600	90.0	89.0	Measured 7' from engine
17' Fiberglass	70	5100	88.5	86.0	Measured 8' from engine
17' Fiberglass	85	5000	93.0	94.0	Measured 8' from engine
17' Fiberglass	115	5000	92.0	93.0	Measured 8' from engine
17' Fiberglass	135	5000	93.0	98.0	Measured 8' from engine
17' Fiberglass	70	5100	88.5	86.0	Measured 3' from engine
17' Fiberglass	85	5000	93.0	94.0	Measured 3' from engine
17' Fiberglass	115	5000	92.0	93.0	Measured 3' from engine
17' Fiberglass	135	5000	93.0	98.0	Measured 3' from engine

FIGURE V-1. OUTBOARD SOUND LEVELS (dBA)

(To convert feet to meters multiply by 0.3048.)



[1]Noise level at which speech communication is barely possible when shouting over a 2-foot distance.

[2]NIOSH ultimate goal limit for 8-hour daily occupational exposure to continuous noise for avoidance of significant hearing damage.

FIGURE V-2. INBOARD MOTORBOAT AFTER-COCKPIT SOUND LEVELS MEASURED UNDER WAY AT MAXIMUM ENGINE RPM (REFERENCE 3)

S/S 292-531 129

Noise levels of 105 dBA for gasoline engines and 110 dBA for diesel engines were measured at the after-cockpits according to the test; however, these extreme measurements did not appear in Figure V-2.

Magrab (Reference 4) studied sound levels of pleasure boats for the purpose of establishing noise criteria. The abstract of his report appears below.

> "The noise emitted by recreational boats presents the following problems: (1) noise pollution to bystanders, (2) communication difficulties on-board, and (3) permanent damage to an individual's hearing. A noise criteria must be determined first in order to solve these problems.
>
> A noise analysis of various common recreational boats and engines was conducted from measurements taken in the field.
>
> Standard test procedures for taking sound measurements exterior to and on-board recreational boats were established. The mean value of noise from large, small, and all motors were found to be 85.4, 80.2, and 82.9 dBA respectively.
>
> A noise level of 65 dBA is considered moderately noisy by most people. Therefore, most all motors emit an unacceptable level of noise to people in boating areas such as lakes, rivers, etc. The problem of communication among individual on-board recreational boats may present a safety hazard and fog situation where warnings of danger must be spoken or ships' whistles and fog signals must be heard. A high noise level such as 82.9 dBA over a long period of exposure may also be damaging to an individual's hearing. Standard test procedures have been established to measure the noise level emitted from recreational boats as a first step to help eliminate the above problems."

Sound level data from the Magrab report is graphically shown in Figure V-3.

Wyle Laboratories recently measured the sound levels from the operator's position of eleven boats (Reference 1). Results are shown in Figures V-4 and V-5. Sound levels were measured at idle or 1000 rpm, at a comfortable cruising speed, and at full throttle. When averaged they appear as shown below.

CONDITION	SPEED (MPH)	SOUND LEVEL (dBA)
Idle	6.2	69.1
Cruise	25.4	82.2
Full Throttle	35.6	90.6

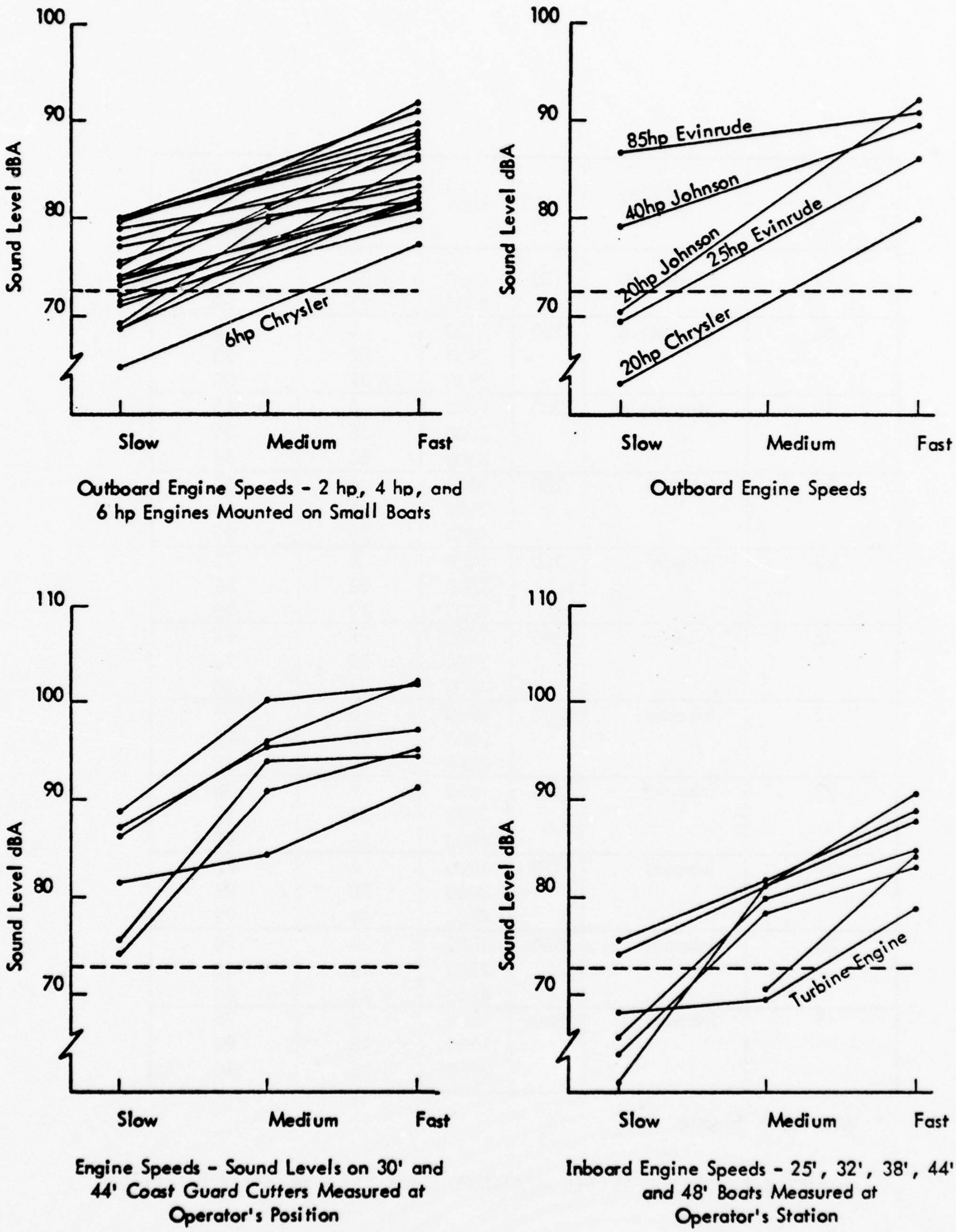


FIGURE V-3. SOUND LEVEL MEASUREMENTS (REFERENCE 4)

BOAT LENGTH (Ft)	POWER TYPE	HP	RPM	SPEED (MPH)	SOUND LEVEL (dBA)
17	Outboard	135	4000	26	82
			5500	37	90
16	Sterndrive	130	1000	5	60
			2800	22	80
			3500	32	90
19	Sterndrive	200	1000	6	65
			2800	28	85
			3500	33	88
22	Inboard	200	1000	6	67
			2800	21	84
			4300	30	93
23	Inboard	235	1000	6	72
			3500	33	82
			WOT*	40	90
25	Inboard	260	1000	7	64
			2800	22	78
			4000	31	90
25	Inboard	200	1000	6	69
			2800	20	78
			3800	30	88
27	Inboard	600	1000	7	78
			3000	36	87
			4800	56	99
27	Inboard	470	1000	6	77
			3000	28	86
			4200	42	92
36	Inboard	660	1000	6	70
			2800	18	80
			4200	25	86
45	Inboard	850	500	6	75
			1500	18	84
			2250	25	90

* **Wide open throttle**

FIGURE V-4. SOUND LEVELS MEASURED ON ELEVEN BOATS (REFERENCE 1)

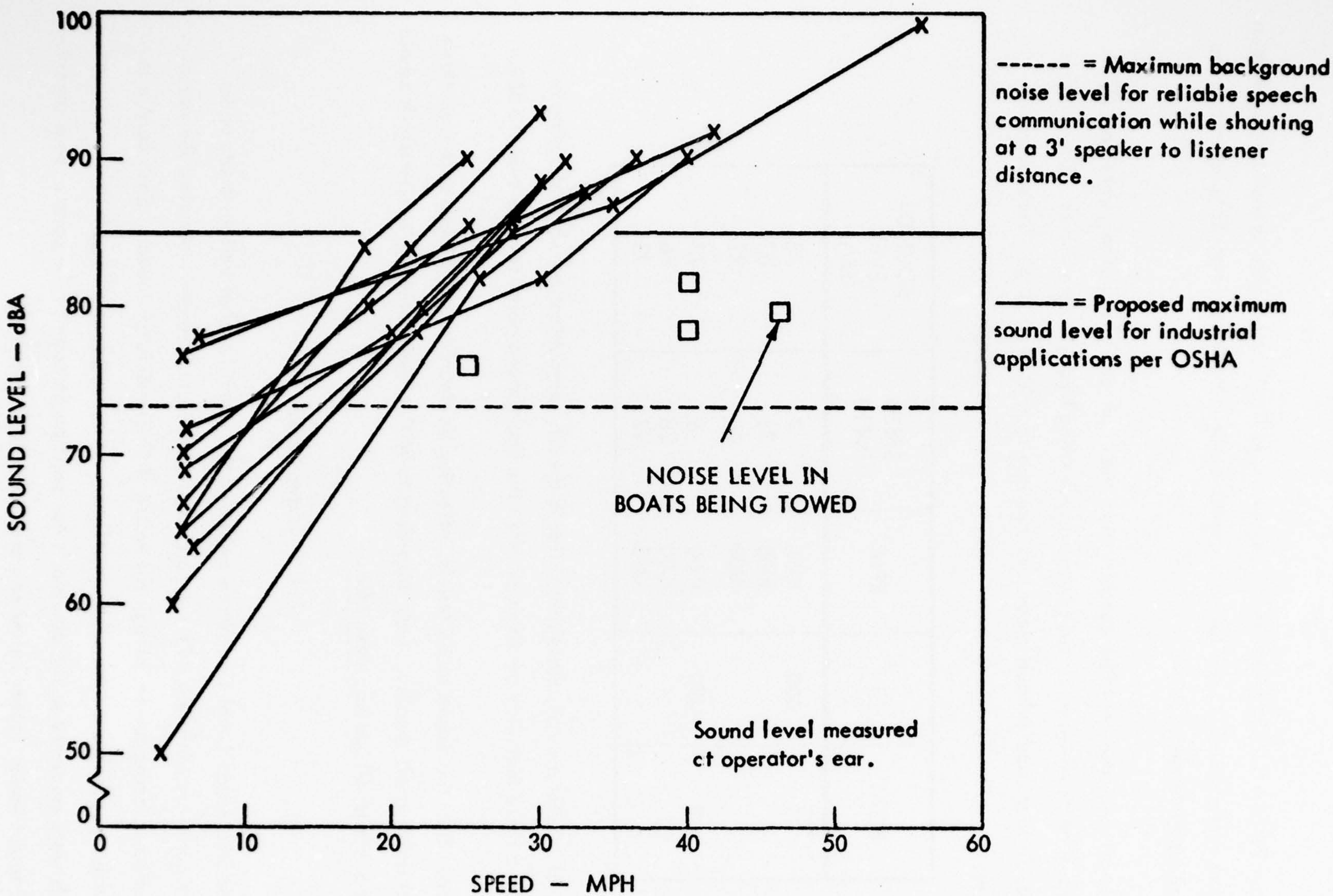


FIGURE V-5. SOUND LEVEL MEASUREMENT ON ELEVEN BOATS

If we consider 73 dBA background noise to be the upper limit for reliable speech communication while shouting (Reference 2), then reliable speech communication is impossible when running at cruising speed or faster.

Two of the boats measured could be considered in the "hot rod" class. They were both 27 ft (8.2 m) deep-V boats powered by twin inboards operating through stern drives. Both had no mufflers and, in fact, had exhaust pipes less than one foot (0.3 m) long. Their statistics appear below.

BOAT	HP	RPM	SPEED (MPH)	SOUND LEVEL (dBA)
1	600	1000	7	78
		3000	36	87
		4800	56	99
2	470	1000	6	77
		3000	28	86
		4200	42	92

Morgan, et al. (Reference 5), state that reliable speech communication while shouting is impossible at a three foot (0.9 m) distance when the background noise level is over 73 dBA.

As can be seen from the above sound levels, effective communication is impossible from three feet (0.9 m) away at all speeds. And, according to Miller (Reference 6), temporary threshold shifts could occur at all speeds, even idle.

2.1.1 Water Noise

In 1973, the SAE Sound Level Committee measured the sound level of various boats under various configurations (Reference 7). A portion of their tests included measuring the sound level of four boats being towed through the water at their maximum speeds. Each boat was equipped with an outboard motor. The propellers were removed and the gearcase was faired. Sound levels were measured at the operator's ear position on each of the boats. Boat specifications and sound levels appear below and are shown in Figure V-5.

BOAT NO.	LENGTH (FT)	HULL MATERIAL	HULL SHAPE	OUTBOARD (HP)	SPEED (MPH)	SOUND LEVEL (dBA)
1	14	Aluminum	?	25	25	78.0
2	15	Fiberglass	Cathedral	65	40	81.5
3	15	Fiberglass	V	65	40	78.5
4	17	Fiberglass	Cathedral	135	46.2	79.5
					37.8	79.4

Although the boat sample was small, it appears as if the water/hull interaction on boats with complicated hull bottom shapes creates slightly more noise than does the less complicated hull shapes. However, it remains unknown whether the higher noise level was due to the hull shape itself, or the fact that there may have been more wetted surface on the cathedral hulls.

If the results were averaged, one could conclude that the sound level created by the water noise alone at the operator's station on a boat traveling at 39 mph (62.8 kph) would be over 79 dBA or enough to mask reliable speech communication and cause temporary threshold shifts.

2.1.2 Wind Noise

Professor A.R. Howell of the University of Windsor conducted a study in 1973 for Outboard Marine Corporation (Reference 8) wherein he measured the sound levels within the ears of ten subjects. The sound was produced solely by the wind as the subjects rode on top of a coasting truck moving at speeds from 20 to 70 mph (32.2 to 112.7 kph).

As Figure V-6 shows, wind induced noise varied from a low of 88 dBA at 20 mph (32.2 kph) to a maximum of 113 dBA at 70 mph (112.7 kph). The dotted lines show that the mean wind noise within the operator's ears measures over 100 dBA at 40 mph (64.4 kph). Since many small, open boats are capable of speeds over 40 mph (64.4 kph), it may be assumed that operators are subjected to sound levels of this magnitude from wind alone.

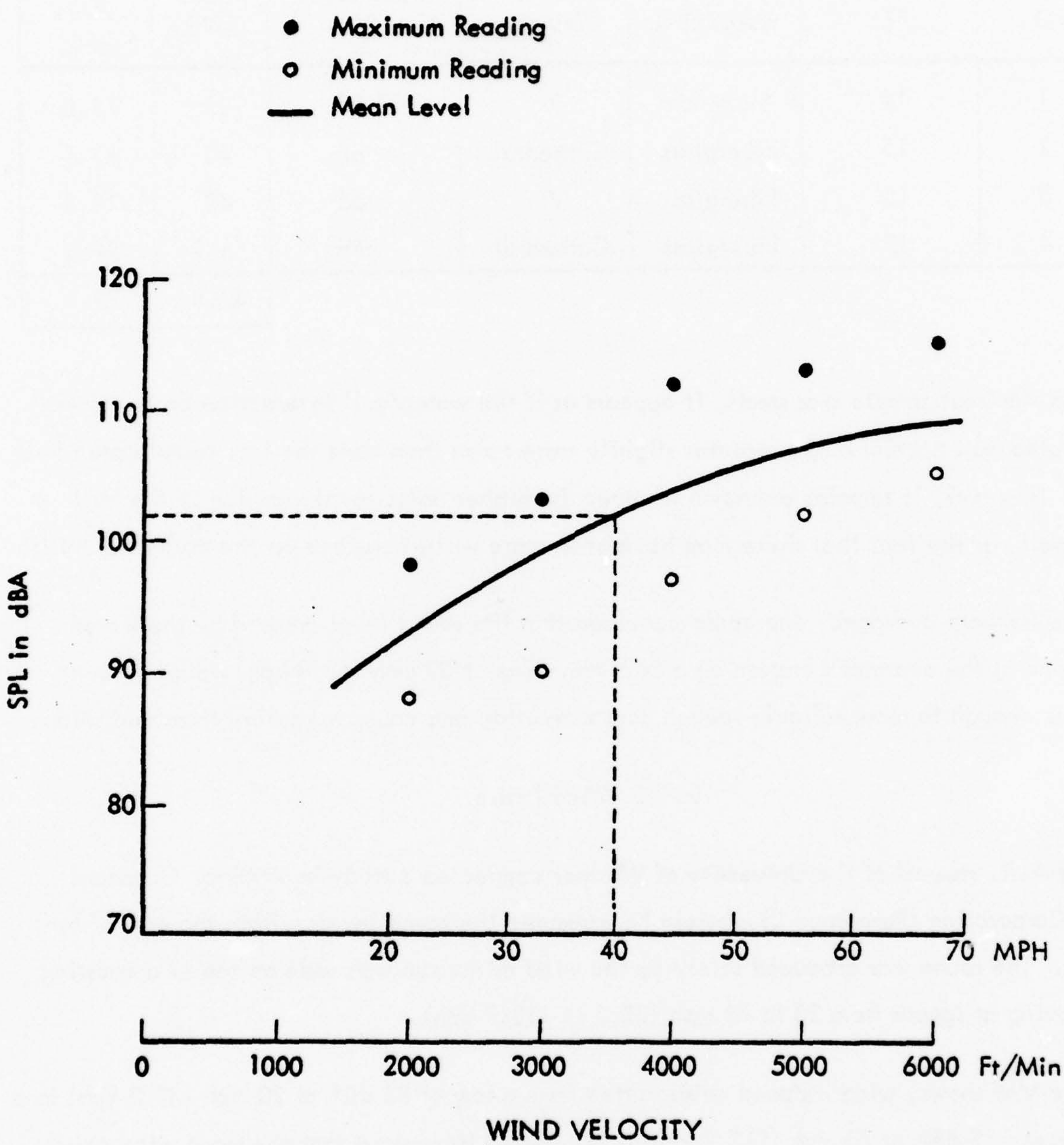


FIGURE V-6. NOISE LEVEL VERSUS WIND VELOCITY

A problem does exist from the standpoint of applying the data. If one looks at the total sound levels measured on boats being powered at similar speeds, the measured sound level at the operator's stations are considerably less than those measurements for wind alone per the Howell study.

This creates many questions. How valid is the Howell data? Are wind-induced sound levels really that loud to the operator? Howell used a special type of microphone, developed especially for the experiment, which was planted inside the subject's ear. The data was modified somewhat to coincide with what the sound level would have been at the center of the subject's head if he were not there. Can this data be compared directly to data recorded on commercially available sound measuring equipment?

Normally experimentors use wind shields over microphones to eliminate the effects of the wind passing over the microphone when measuring the sound level on moving vehicles. Perhaps this isn't valid. Perhaps the perceived sound levels on moving vehicles are actually quite a bit higher than we now believe.

This area should be carefully studied since Howell's wind-induced noise levels were high enough to cause complete masking of reliable speech communication, temporary threshold shifts, permanent hearing losses if sustained for a long enough period of time, and possibly other physiological problems.

3.0 SUMMARY

Two hundred eleven (211) sound level measurements made from the operator's position of all boats under power and referenced were combined and are presented in Figure V-7.

As can be seen, sound levels varied from 60 dBA through 102 dBA with a mean of 83 dBA. According to the referenced sources, a significant number of the data points fell with the range of sound levels that:

- mask effective speech communication.
- cause temporary threshold shifts.
- contribute to permanent hearing damage.
- may cause other physiological problems which could contribute to the cause of collisions.

More startling were the results of the experiments on wind induced noise levels measured inside the human ear. If one can accept the results of the experiment as being valid, the noise that the operator of an open runabout traveling at 40 mph (64.4 kph) hears from the wind passing his head is approximately 100 dBA. Obviously, when water noise and machinery noise are combined with this, the resultant sound level that the operator actually perceives could be significantly higher. For example, if we have two similar noise sources operating simultaneously, the sound energy generated by the two sources will combine to give a value double that which would result from either source operating alone. The resulting sound pressure level in decibels from the combined sources will be only three decibels higher than the level produced by either source alone (since the decibel scale is logarithmic rather than linear). In other words, if we have two sounds of different magnitude, then the level of the sum will always be less than three decibels above the level produced by the greater source alone. If the two sound sources produce individual levels that are different by 10 decibels or more, then adding the two together produces a level that is not significantly different from that produced by the greater source operating alone.

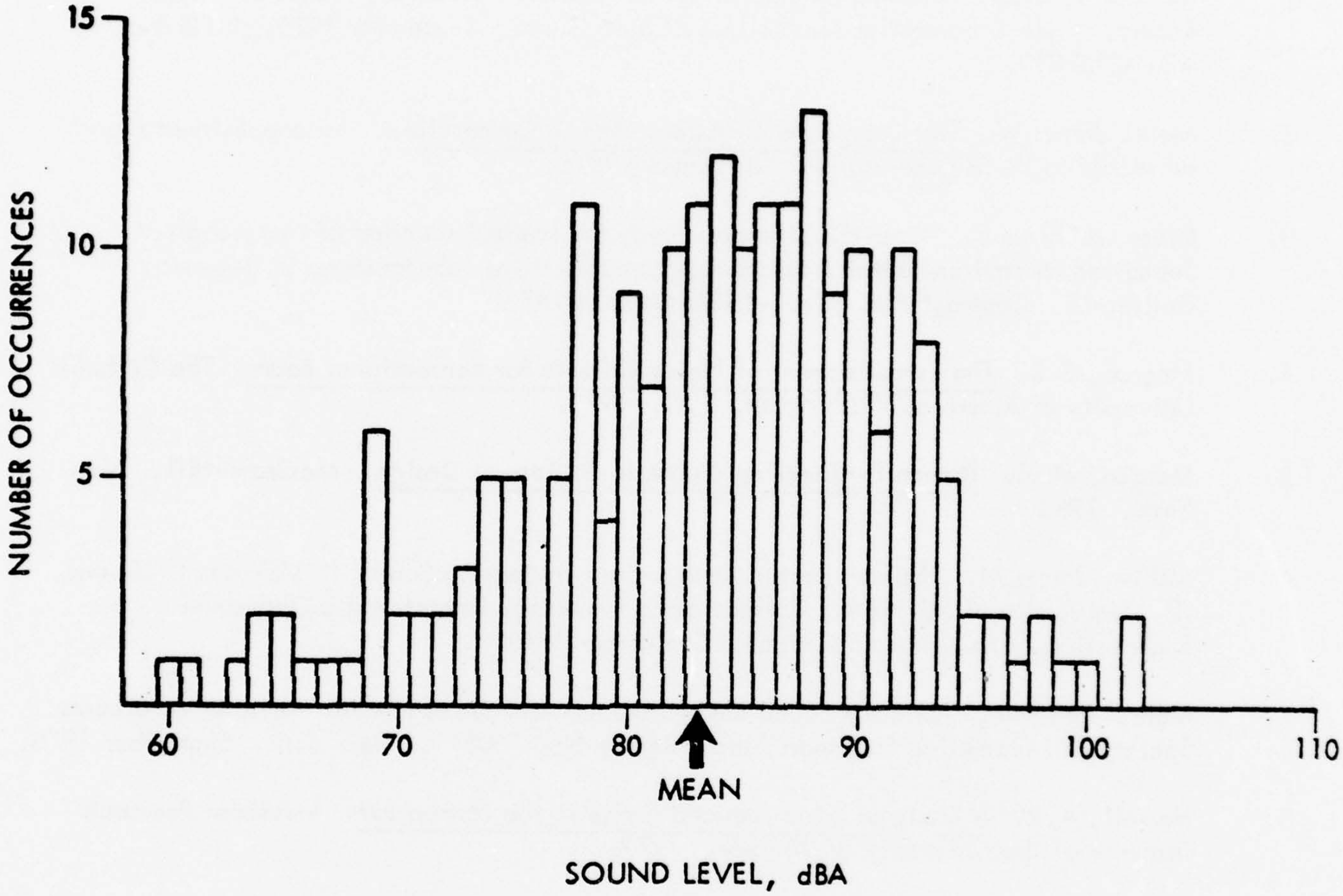


FIGURE V-7. FREQUENCY OF OCCURRENCES FOR SOUND LEVELS

REFERENCES

1. MacNeill, et al. "Recreational Boat Safety Collision Research - Phase I." Final Report. Wyle Laboratories for the U.S. Coast Guard. September 1975. NTIS No. AD-A015-819.

2. Mohr, James W. Test Data from Outboard Marine Corporation. An unpublished report submitted to Wyle Laboratories. 20 January 1975.

3. Roper, William E. "Cost Effectiveness Study for Noise Reduction of Motorboats." Submitted to Environmental Protection Agency by Wyle Laboratories, El Segundo, California. Contract No. 68-01-1537. August 1973.

4. Magrab, E.B. The Establishment of Noise Criteria for Recreational Boats. The Catholic University of America, Washington, D.C. 1973.

5. Morgan, et al. Human Engineering Guide to Equipment Design. McGraw-Hill. New York. 1963.

6. Miller, James M. "Human Factor Applications in Boating Safety." Volumes I, II, and III. University of Michigan, College of Engineering, Department of Industrial Engineering, Ann Arbor, Michigan. September 1973.

7. Mohr, James W. "Exterior Sound Level Measurement Procedure for Pleasure Motorboats." Society of Automotive Engineers, Inc. Report No. 730811. New York. September 1973.

8. Howell, A.R. A Study of Wind Induced Noise in the Human Ear. Industrial Research Institute of the University of Windsor. 1973.

SECTION VI –
EXPANDED INDUCED ENVIRONMENTAL DATA ACQUISITION PROGRAM

1.0 OBJECTIVE

The objective of the data measurement program is to obtain environmental data of subsystems induced by boats during boating operations in water and during transportation. The data will be reduced to obtain the characteristics of subsystem environments and to provide exploratory information of the induced environment. The purpose is for inclusion into a subsystems environment manual for dissemination and usage by boat designers/builders and owners/operators for safer boat subsystems and operations.

2.0 SCOPE

The scope of an expanded induced environmental data acquisition program will include boat operations (in water) and boat transportation activities. A systematic and logically developed plan will be designed to generate, to reduce, and interpolate the maximum results from minimum data. The type of data will include:

- Shock/Vibration effects - structural, control and instrumentation, and engine subsystems
- Acoustics (Noise) effects - human element
- Center-Of-Mass Acceleration effects - force loading total boat system
- Temperature effects - as a function of time
- Solvents effects - a function of accumulation

3.0 GENERAL

The proposed boat classification matrix has 1296 potential categories or cells. It is not feasible to gather data on this many different groupings. Obviously, some of these cells will be empty or negligible, thereby greatly reducing the task. It is apparent that the test designs should be planned to permit the maximum usage of the smallest amount of test data through interpolation and/or extrapolation. This scheme has two inherent advantages:

1. Economical utilization of small amount of data making possible the derivation of data for a large number of cells.
2. In order to interpolate or extrapolate data, it will be necessary to derive some multipliers and methods of going between cells. The method and the multipliers could be used by boat designers/manufacturers to arrive at the environmental boundaries for specific boats that may not be included in the matrix.

The purpose of providing information on boat/subsystems environmental boundaries is to enable designers and builders to better evaluate design requirements for boats and associated equipment and to assist in determing the usefulness of existing and proposed standards as well as providing practical estimates of boats and associated subsystems life cycles.

Is is obvious that regardless of what designers/builders do to provide more reliable, durable, and safer boat systems, that ultimate responsibility lies with the owner/operator. No system, boat included, is beyond abuse and misuse. The boat owner/operator makes decisions that affect the safety of himself and others almost continuously when operating the boat. The human element is an integral part of boating. In recognition of the human aspect of boating and its proneness to certain accident type situations, and with a better understanding of subsystem environmental effects, boats and associated subsystem components can be designed that more effectively compensate for human error and, thereby, provide a greater margin of safety for the boater.

4.0 APPROACH

The basic approach for test design is as follows:

1. Narrow down the boat classes to a feasible grouping.
2. Determine those classes (cells) most desirable for which to collect test data that will permit the derivation of the multiplier factors:

    a. Hold boat class constant and vary the parameter of interest (e.g., shock level).

    b. Hold parameter of interest constant and vary the boat class.

    Figures IV-1 and VI-2 illustrate the two concepts in Step 2 above.
3. Derive multiplier factors to estimate values for untested cells.
4. Compute estimated values for matrix.

The overall process is depicted in Figure VI-3, Derivation of Subsystems Environment Data for Untested Cells. The process will be repeated for all parameters (induced environmental factors) of interest. This information will constitute the basic data for a Subsystems Environment Manual as shown in Figure VI-4.

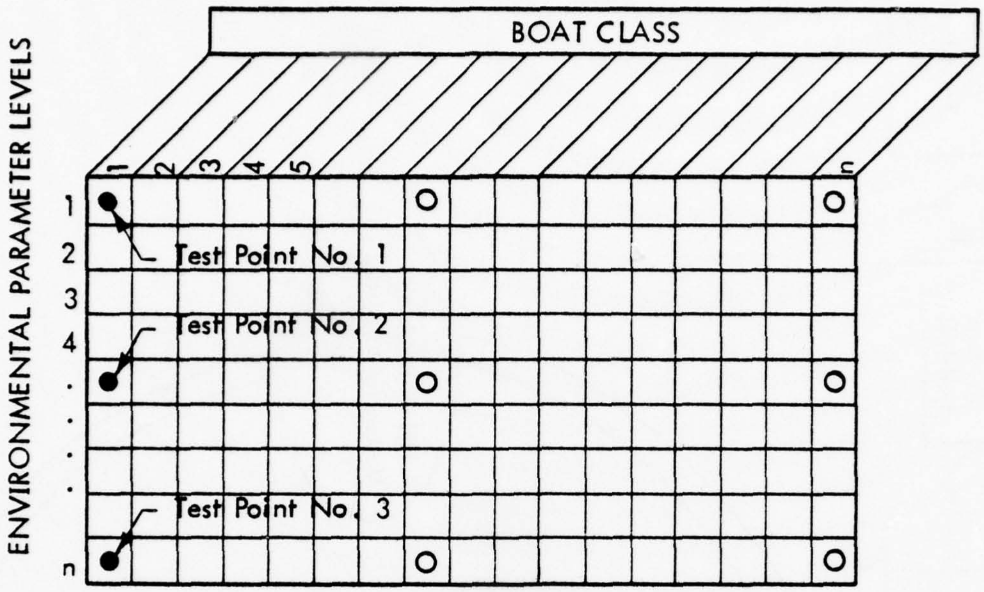


FIGURE VI-1. HOLDING BOAT CLASS CONSTANT AND VARYING THE LEVEL OF PARAMETER OF INTEREST

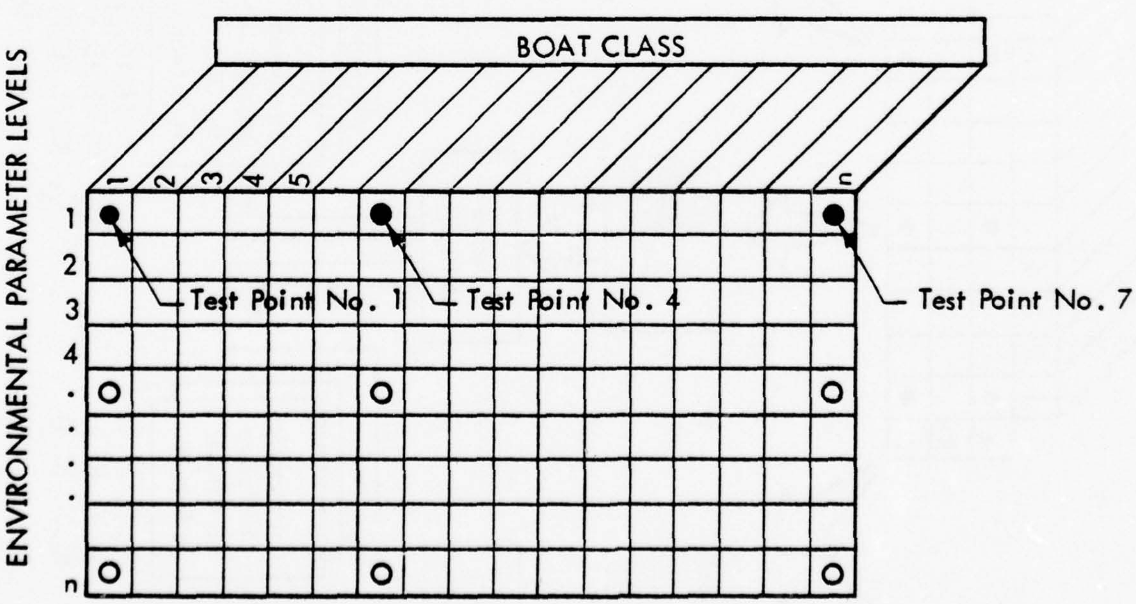


FIGURE VI-2. HOLDING LEVEL OF PARAMETER OF INTEREST CONSTANT AND VARYING THE BOAT CLASSES

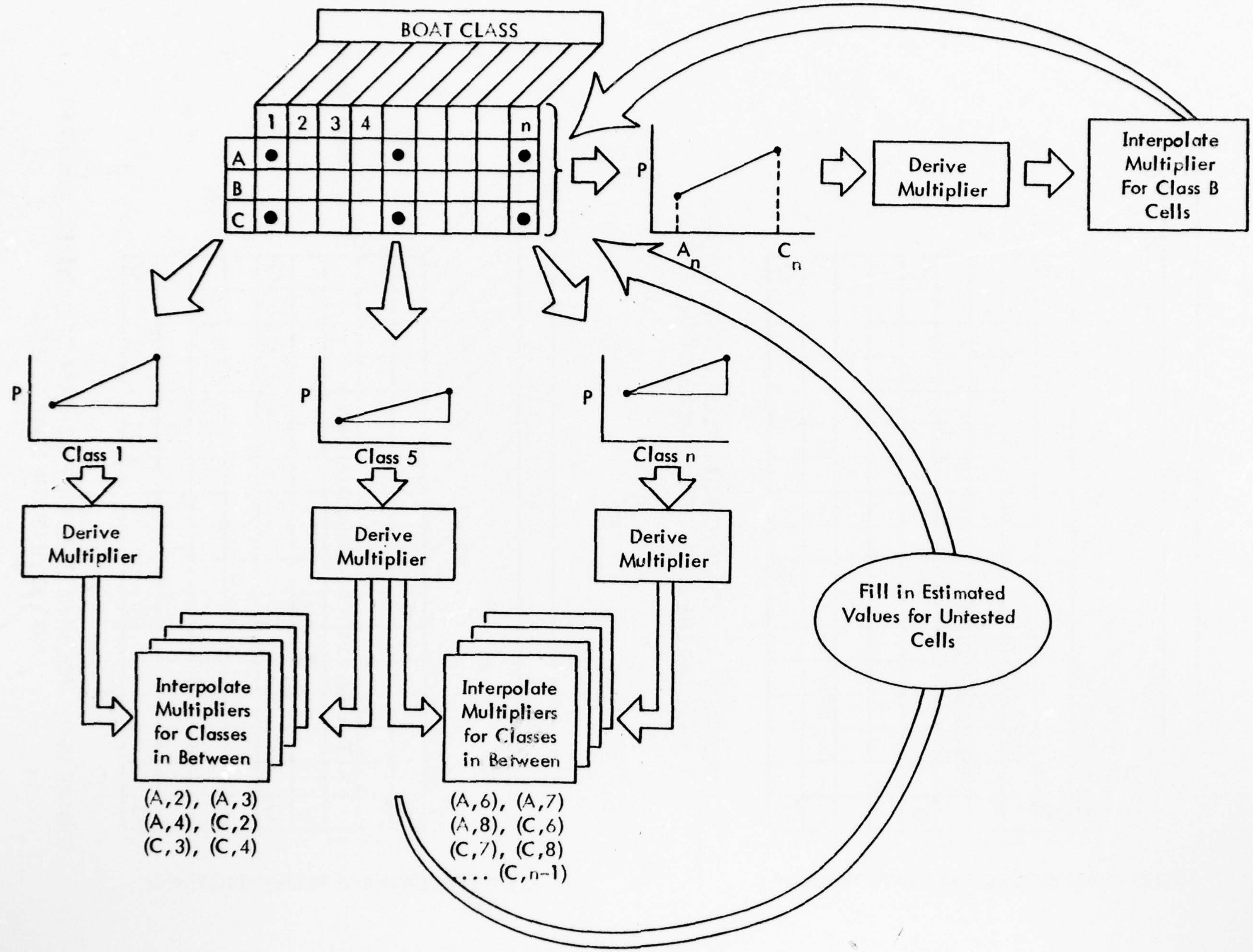


FIGURE VI-3. DERIVATION OF SUBSYSTEMS ENVIRONMENT DATA FOR UNTESTED CELLS

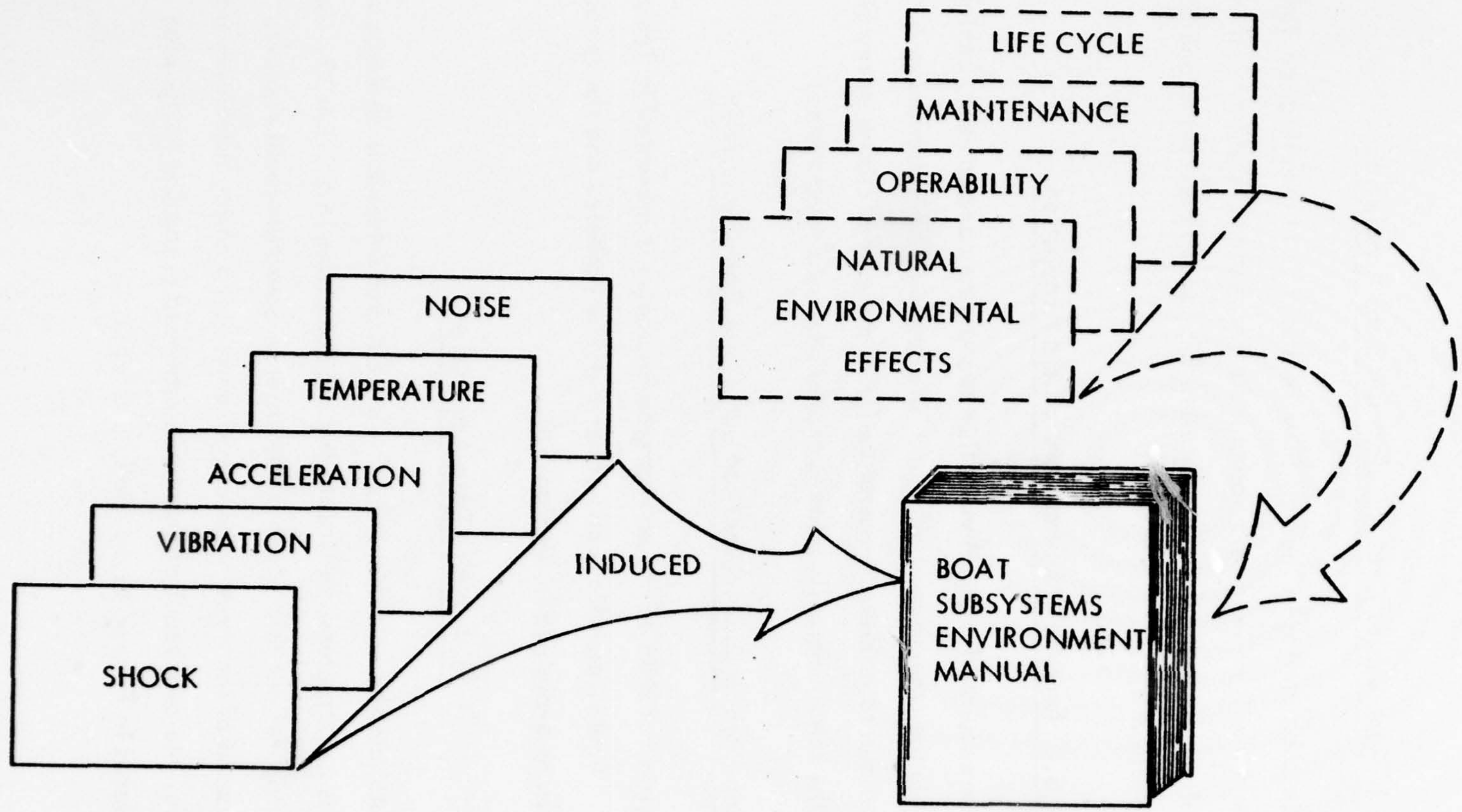


FIGURE VI-4. BASIC DATA FOR SUBSYSTEMS ENVIRONMENT MANUAL

5.0 DATA ACQUISITION

5.1 Approach to C-M Acceleration Data Acquisition

Several tests run at Wyle Laboratories in the past have included C-M acceleration data. This information is available and will be used as a basis for further testing. Data analysis will include the measurement of peak and average induced forces for different water and boat classes as described in Section 3.0.

5.2 Approach to Temperature Data Acquisition

Temperature data will be acquired for locations within the engine compartment, behind the instrument dash and inside the storage compartment. The data will be presented as a temperature vs. time plot normalized to ambient temperature for as many boat classes as are essential to interpolate data for the remaining cells (classes and/or levels of temperature).

5.3 Approach to Shock/Vibration and Noise Data Acquisition

The approach for acquisition of data on shock/vibration and noise is presented in Tables VI-1 and VI-2, respectively. Again, essential cells of data will be gathered and the remaining cells will be interpolated as explained in Section 3.0.

5.4 Noise Data Acquisition

The researched noise data and the noise data which was retrieved under this contract and described in Section V is not structured to fit into the plan proposed in Section VI. As was pointed out, the noise must reflect that which a passenger or operator would receive. It, therefore, must be composed of the three noise components: wind noise, machinery noise, and water noise. Hence, the data required should be retrieved according to the plan outlined in Section 4.0 and depicted in Figures VI-1, VI-2, and VI-3.

5.5 Other Data

In addition to induced environmental data, other data, material, and information should also be an integral part of a Boat Subsystems Environmental Manual. All of these have been discussed in this report and are shown in Figure VI-4. They are the following:

- Natural Environmental Effects
- Operability
- Life as a Function of Maintenance
- Boat Life Cycle

TABLE VI-1. INDUCED ENVIRONMENTAL FACTOR DATA ACQUISITION APPROACH FOR SHOCK/VIBRATION

TEST PROCEDURES	To date no standard test procedures have been specified for the acquisition of shock/vibration data. Shock/vibration data have been grouped together due to the similarity of recording instrumentation.	The boat should be operated at both cruising speed and at maximum controllable speed. (BOAT OPERATIONS)
EQUIPMENT	1. Piezoelectric transducers * will be used to obtain both shock and vibration. 2. Lockheed FM magnetic recorder is adequate for low and medium shock impact, but was not adequate on high shock. Therefore, other alternatives will have to be worked out. 3. Lockheed FM recorder will be used for vibration data. 4. Piezoelectric instrumentation will include a Model 221E accelerometer and an accompanying Model 2640 charge amplifier.	
EQUIPMENT CALIBRATION	The accelerometers should be calibrated prior to each data acquisition period. The charge amplifier and recorder should be checked each day, before and after data acquisition, or anytime the system has been disassembled during tests.	
TEST CONDITIONS	Data will be acquired for three different categories of water conditions (calm, average, severe). Several boats having different hull configurations will be used in an attempt to distinguish a difference in data due only to hull configuration. Random data will be acquired during transportation to and from the test site. This will be accomplished through the use of a second cassette recorder with a random sequence of pulses recorded to trigger the data recorder. The data recorder will be operated remotely by the random program on the cassette recorder.	
INSTRUMENTATION LOCATIONS	Shock Data — Shock data will be obtained along the hull sections where extreme pressure fluctuations may be expected, i.e., water line interaction region on bottom surfaces. Transducers will be mounted perpendicular to the surface at the measurement location on the inside surface. Shock data will be acquired at the water line interaction region and also at locations where fuel tanks or radio/navigation equipment might be located. Vibration Data — Vibration data will be obtained from interior structures, i.e., bulkheads, engine cover, console. Of particular concern will be areas for the location of fuel tanks, instrumentation, wiring viaducts. These data will be obtained by the same methods employed for shock data. Since the levels will not be as high, different transducers will be used having different sensitivity values.	
DATA ANALYSIS	Shock Data Analysis — Since the data of interest will only include the boat subsystem environment, no attempt at describing the water characteristics from the data will be made. Although the general water conditions will be described for each data run, the shock data will be reduced to determine maximum and average values for acceleration level and shock duration. Data presentation will be in the form of PSD plots along with interpretation. Vibration Data Analysis — Since vibration is tied very closely to engine speed, vibration data will be taken at different values of rpm. Once again, PSD plots will be run and correlated with both rpm and number of prop blades.	

* The frequency component of this data is expected to be greater than 200 Hz; therefore, strain gage accelerometers have been ruled out.

TABLE VI-2. INDUCED ENVIRONMENTAL FACTOR DATA ACQUISITION APPROACH FOR NOISE

TEST PROCEDURES	Standard Test Procedures - Peak Pass-by dBA Levels. The procedure for obtaining acoustic data will be in such a manner that the results will be compatible with data taken in previous studies.
BOAT OPERATIONS	The boat should be brought up to maximum speed as rapidly as possible without inducing bounding, wave-slapping motion. The side of the passing boat should come as close as possible (less than two feet (0.6 m)) to the floats.
EQUIPMENT	To perform the measurements, a sound level meter, meter calibration and recording mechanism is required. The recording mechanism is required because the available sound level meter (Model 2203) is not equipped with a "max hold" circuit. The sound level meter should have a "fast response" mode and an A-weighting network conforming to internationally agreed stands. The microphone and sound level meter should be sensitive enough to record an ambient noise level of 45 dBA. The microphone should have a grazing (90°) incidence response that is within ± 1 dB to 5 kHz and within ± 2 dB from 5 to 10 kHz.
EQUIPMENT CALIBRATION	The sound level meter should be calibrated at the beginning and end of each day. It is not expected that the sound level meter will require adjustment each day. However, the calibration procedure will provide a check to confirm that the system is in working order each day, all day. The batteries should be checked periodically throughout the period of use of the sound level meter.
TEST CONDITIONS	No reflecting surfaces should be within at least an 80 ft (24.4 m) radius of the boat. The boat should be oriented parallel to the direction of the pass-by boat. The wind speed should be less than five knots if commercially available windscreens are used. If the NBS windscreen is used, the measurements can be made with winds up to 20 knots. No measurements should be made in the rain. Three floats should be placed in a line parallel to and 50 ft (15.2 m) from the nearest side of the boat. The floats should be 50 ft (15.2 m) apart with the center float aligned with the center of the boat. For boats driven by engines with a total of 25 hp and less, the start of the pass-by run should be 100 ft (30.5 m) from either side of the center float. For boats with engines whose total horsepower is greater than 25 hp, the start of the run should be 200 ft (61 m) from either side of the center float.
INSTRUMENTATION LOCATION	<u>Microphone Orientation</u> — The microphone should be mounted with its diaphragm parallel to the water surface (i.e., the sound level meter should be perpendicular to the water), and five to six feet (1.5 to 1.8 m) from the surface of the water.
DATA	<u>Number of Pass-Bys</u> — The qualifying boat should make four (4) pass-bys; two from left-to-right and two from right-to-left. The four peak dBA levels should be recorded and then averaged; summed and divided by four. <u>Accuracy of Results</u> — The average value of the peak pass-by dBA level will be within ± 2 dBA of the true mean 95% of the time.

6.0 DATA APPLICATION

In Section III, it was shown that there is direct relationship between the environmental stressors on a subsystem, part, or component and its failure proneness and failure characteristics. There is, therefore, a strong link between environmental stressors and reliability engineering and the designer/manufacturer must be capable of looking at them together. Appendix C, Failure Physics and Environmental Stressors, describes the method for providing the design engineer with another design tool and how to apply it to the design situation.

APPENDIX A — REDUCED DATA FOR 1974

Appendix A contains the shock duration data for several categories as follows:

- Figures A-1 through A-25 — Small boats data
- Figures A-26 through A-29 — Hatteras yachts data
- Figures A-30 through A-33 — UL data
- Figures A-34 through A-37 — AMF data

The analysis of this data was presented in Section IV, Paragraphs 1.0 through 3.0.

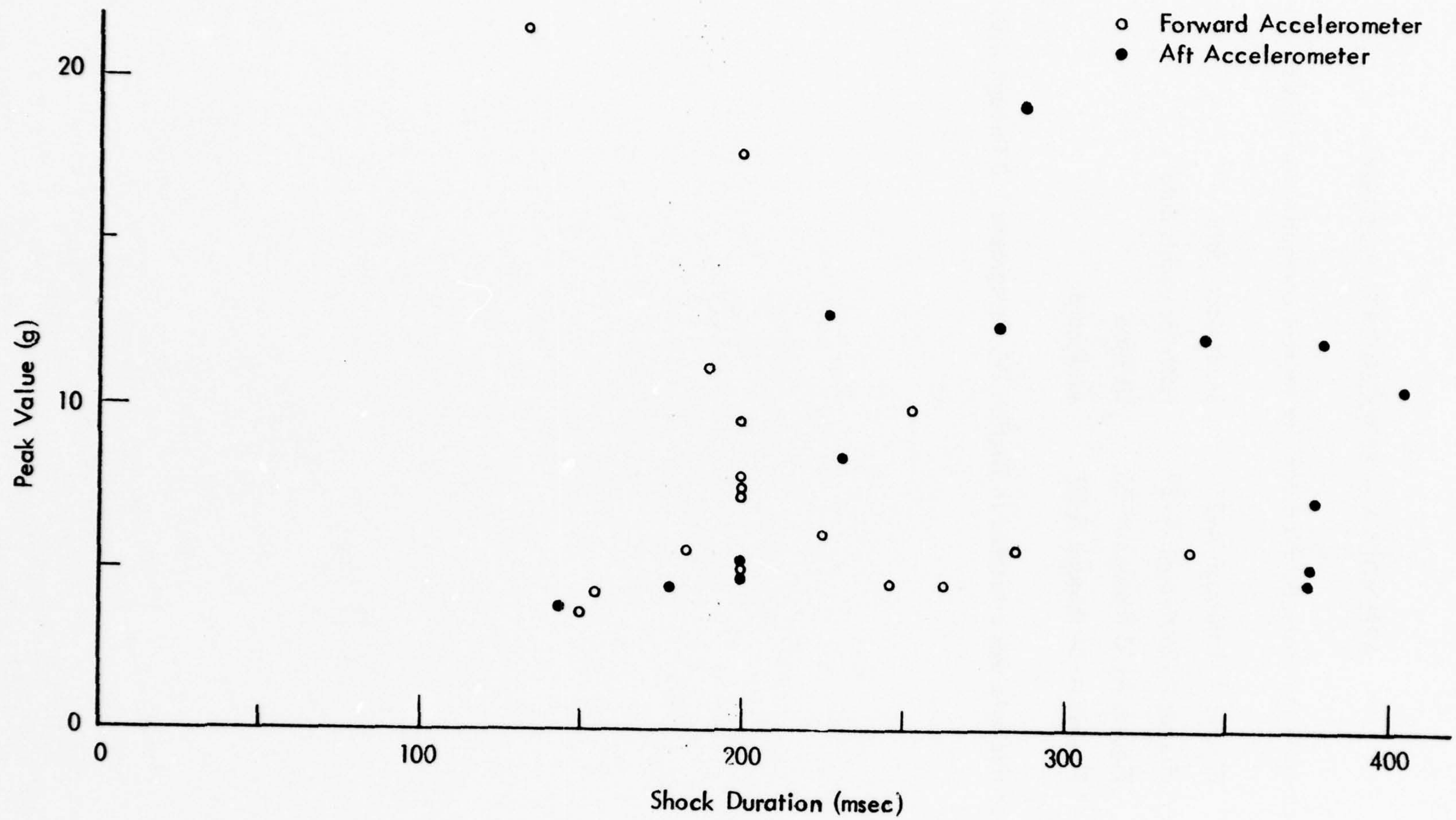


FIGURE A-1. TWENTY-SIX FT (7.9 M) STAMAS FOUNDING DATA

154

156

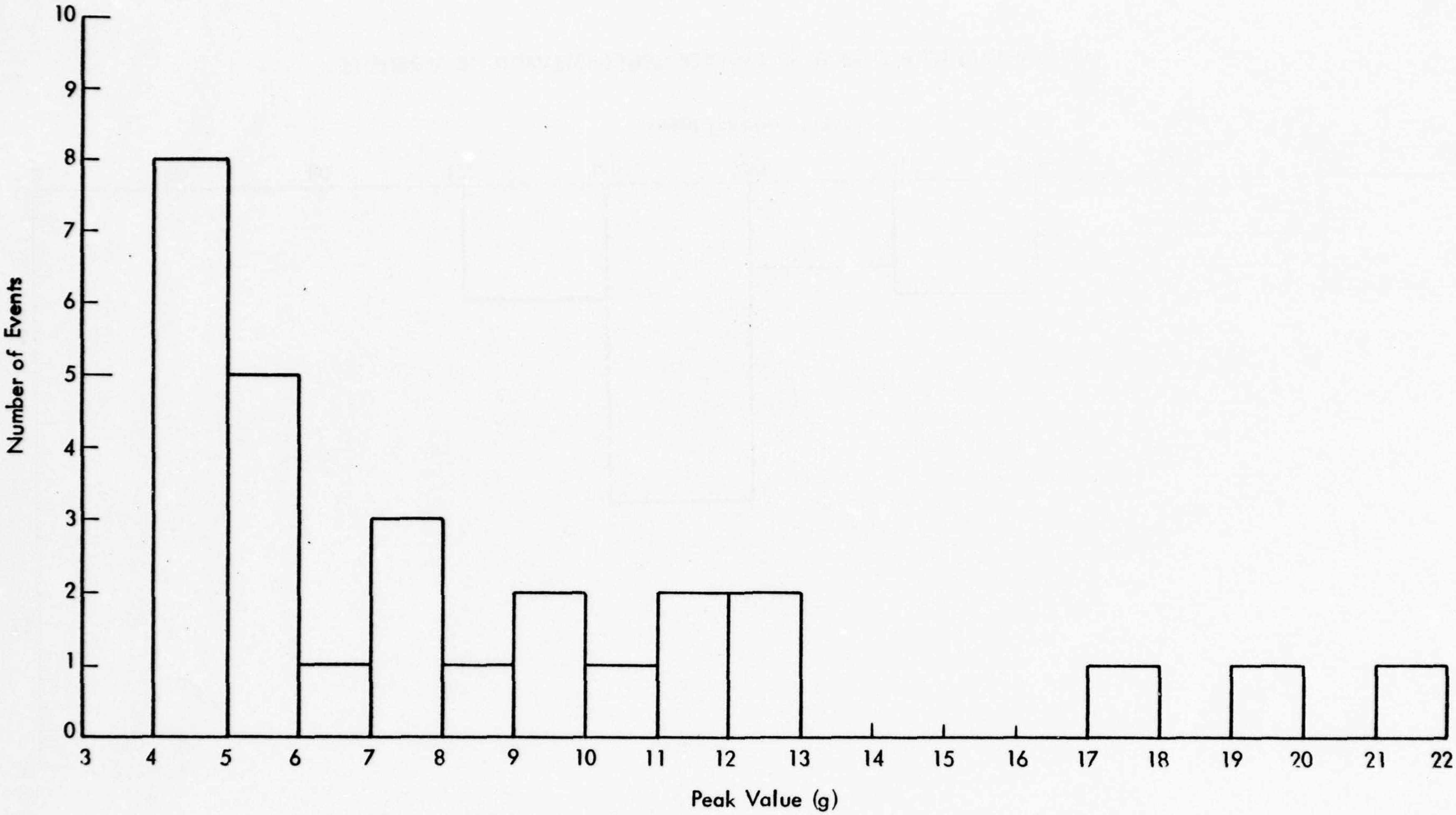


FIGURE A-2. SHOCK PEAK VALUE HISTOGRAM FOR 26 FT (7.9 M) STAMAS DATA

90%

155

157

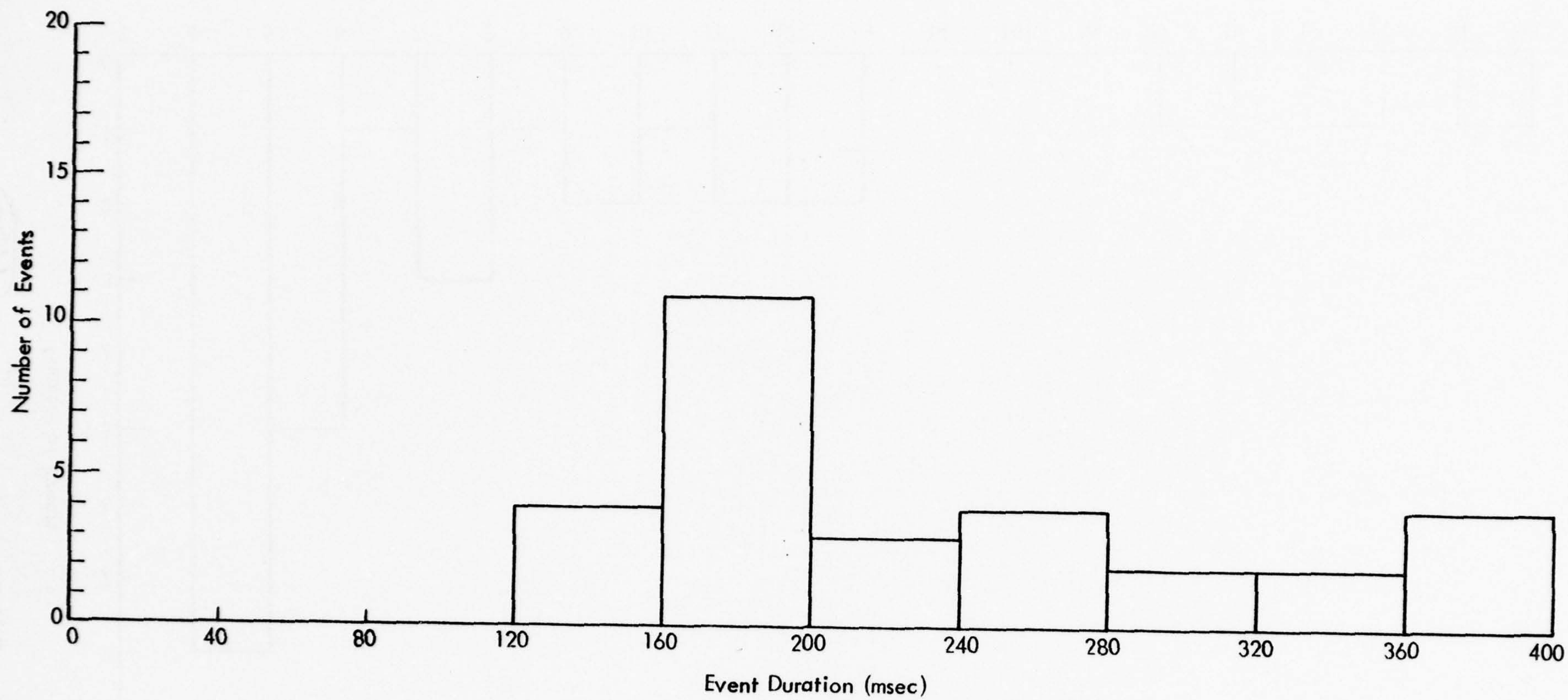


FIGURE A-3. DURATION HISTOGRAM FOR 26 FT (7.9 M) STAMAS DATA

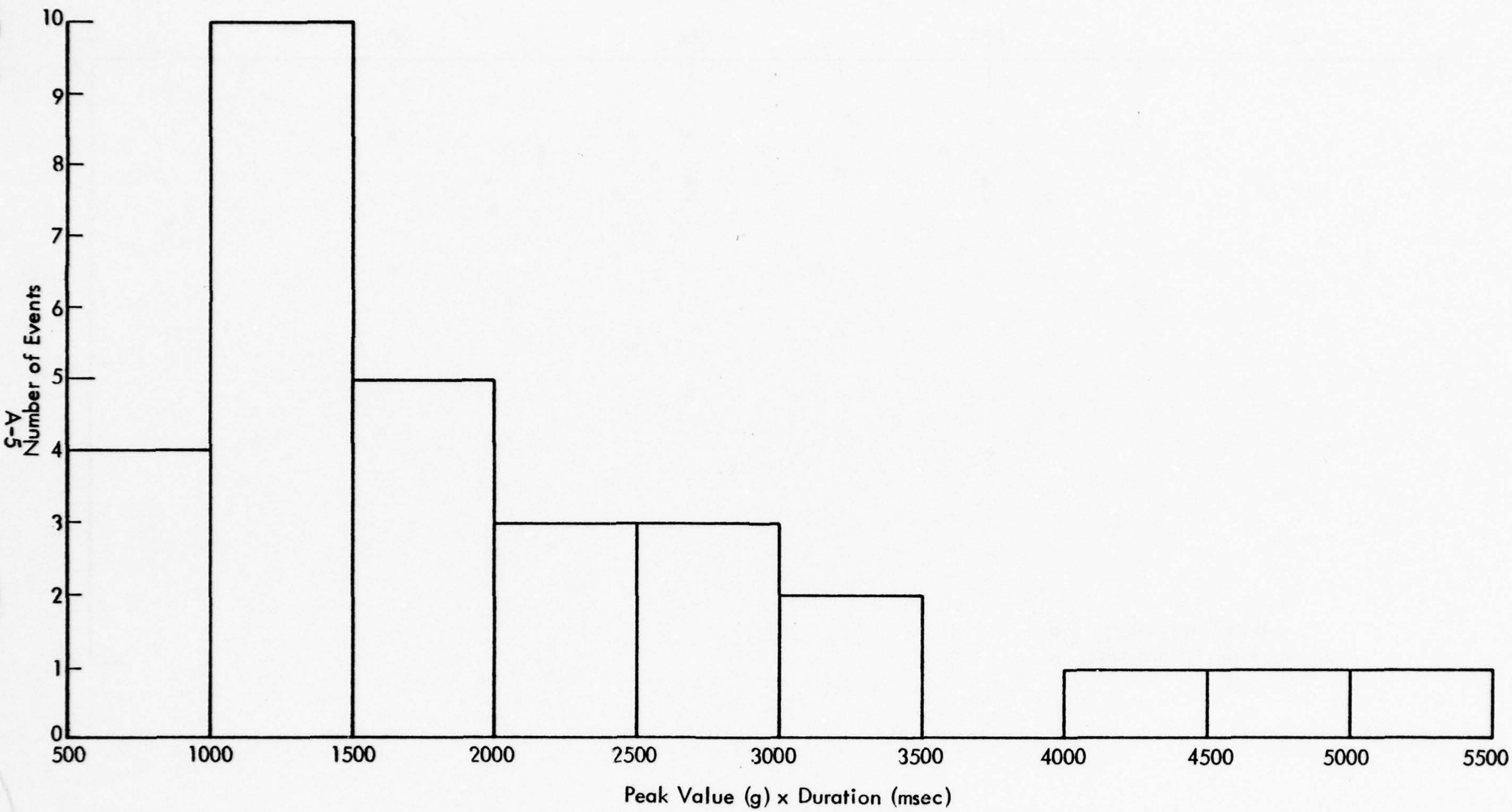


FIGURE A-4. HISTOGRAM OF PEAK VALUE X DURATION FOR 26 FT (7.9 M) STAMAS DATA

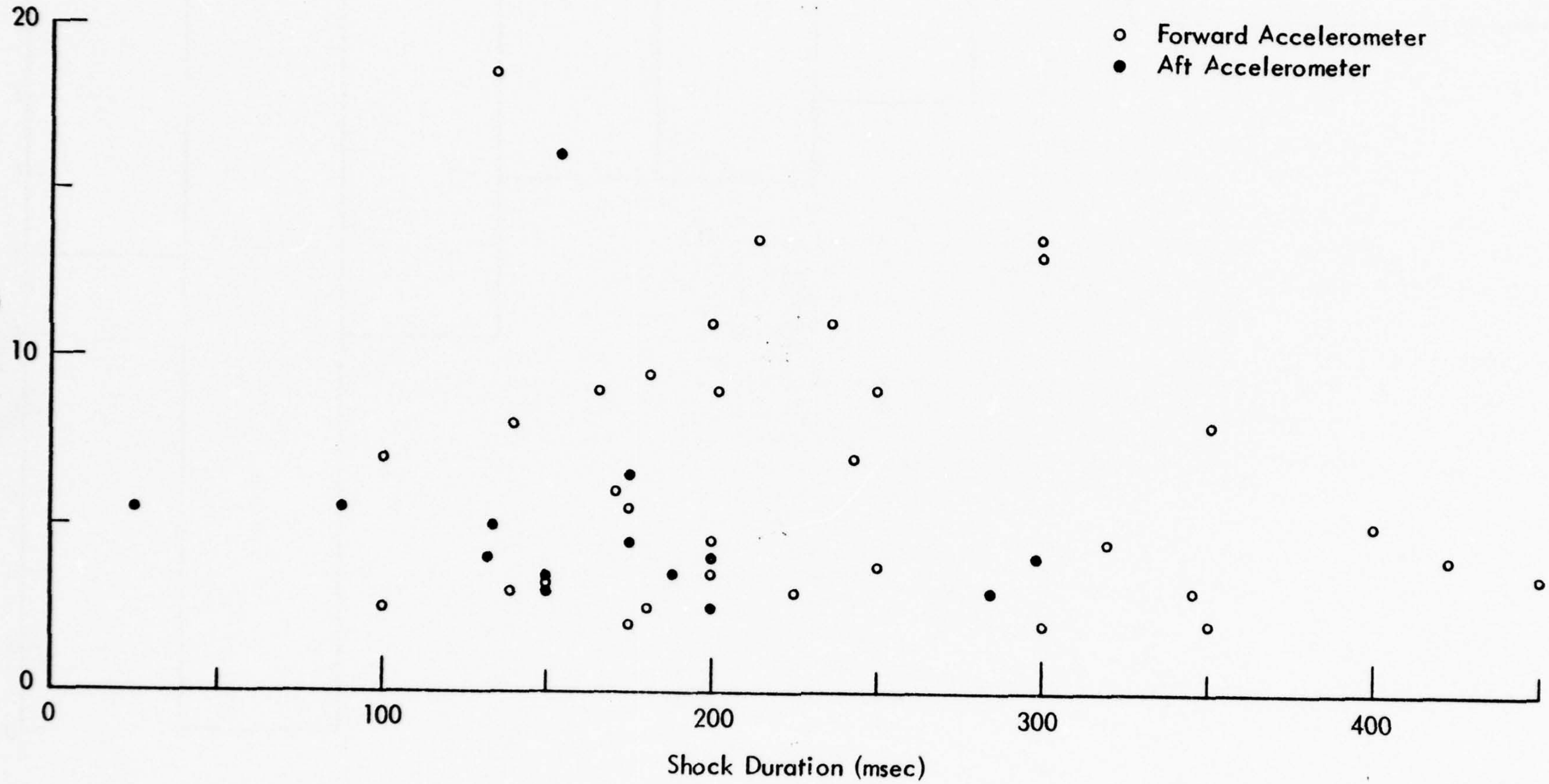


FIGURE A-5. TWENTY-ONE FT (6.4 M) SEABIRD POUNDING DATA, RUN 1

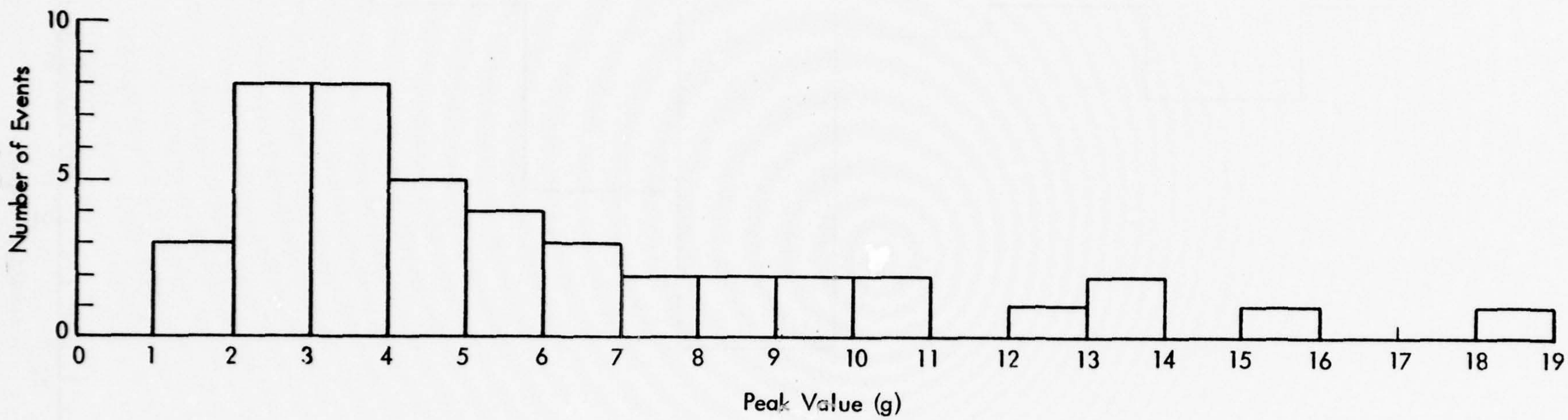


FIGURE A-6. PEAK VALUE HISTOGRAM FOR 21 FT (6.4 M) SEABIRD DATA, RUN 1

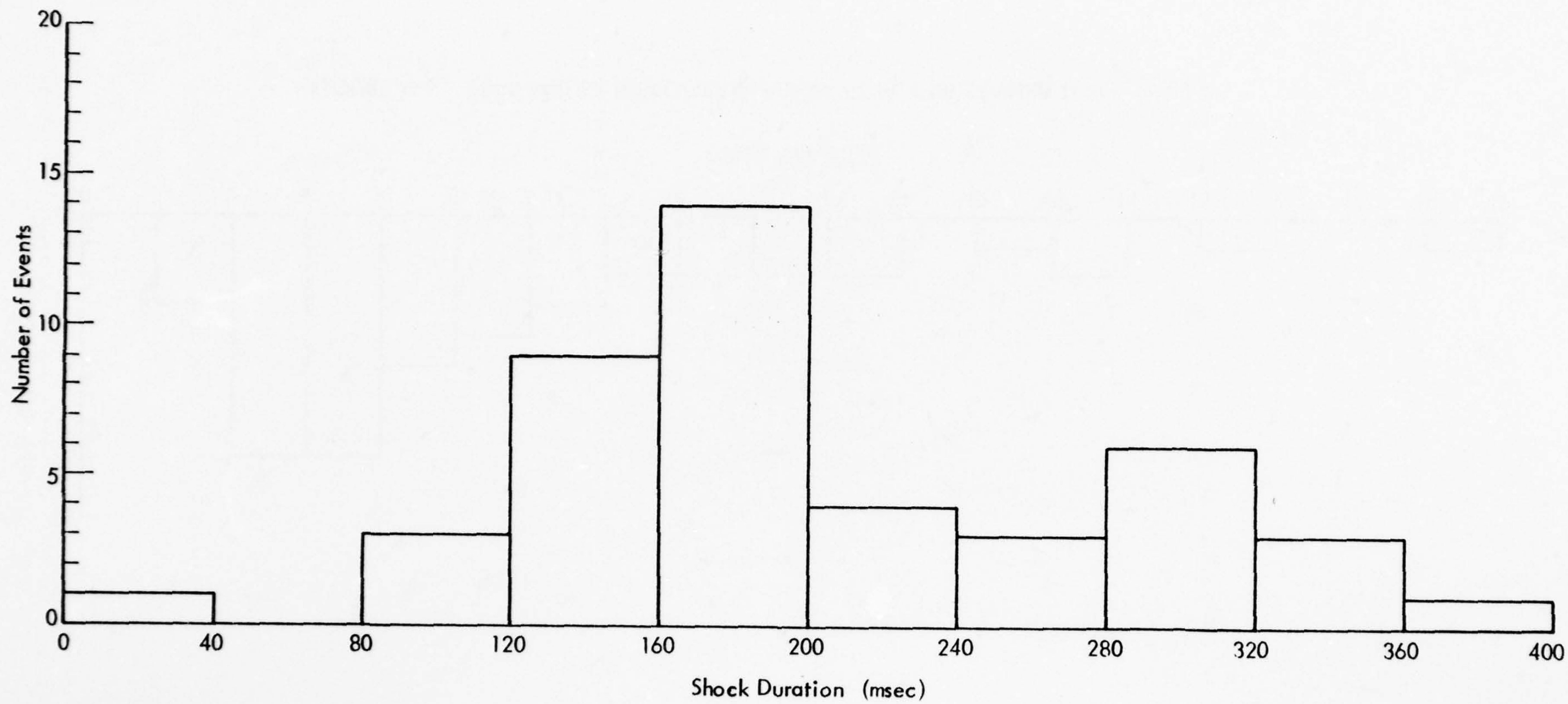


FIGURE A-7. DURATION HISTOGRAM FOR 21 FT (6.4 M) SEABIRD DATA, RUN 1

90%
292-531
(167)
163

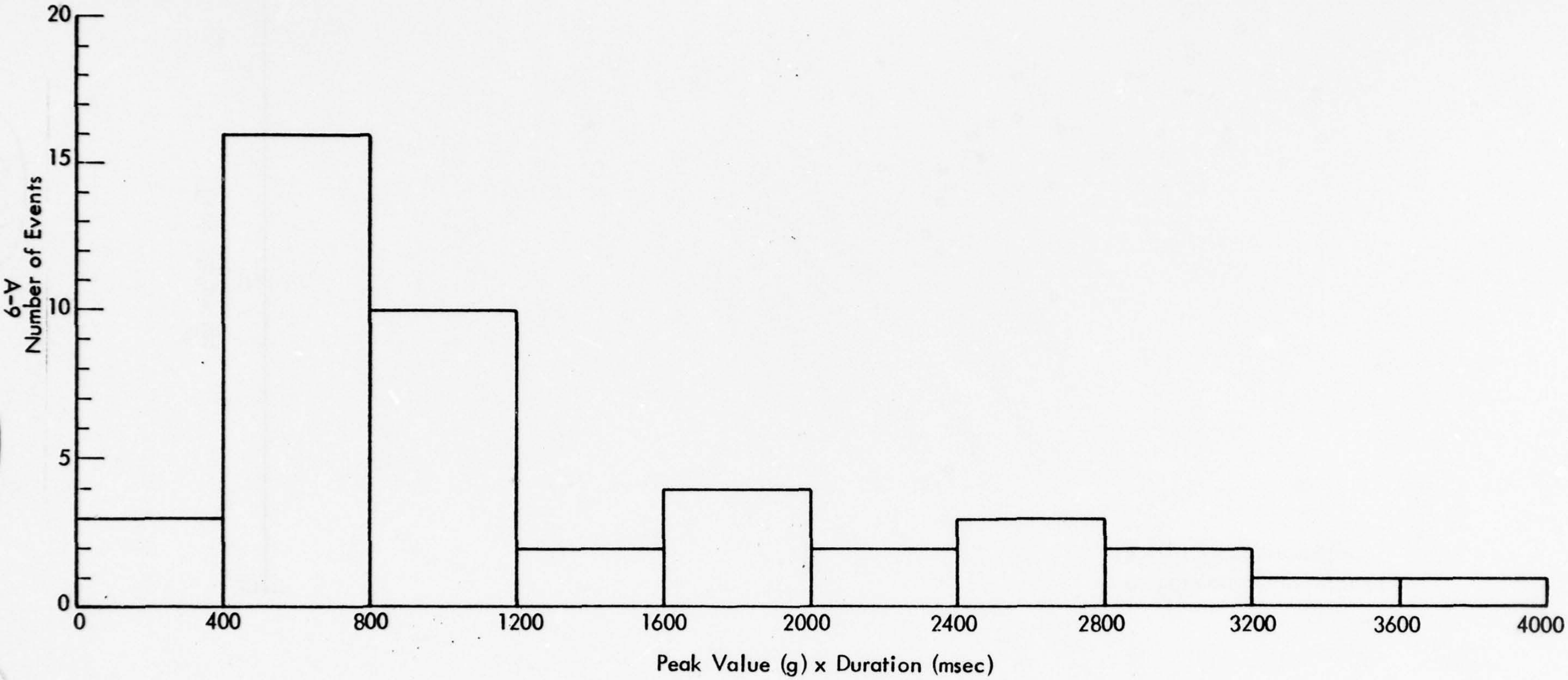


FIGURE A-8. HISTOGRAM OF PEAK VALUE X DURATION FOR 21 FT (6.4 M) SEABIRD DATA, RUN 1

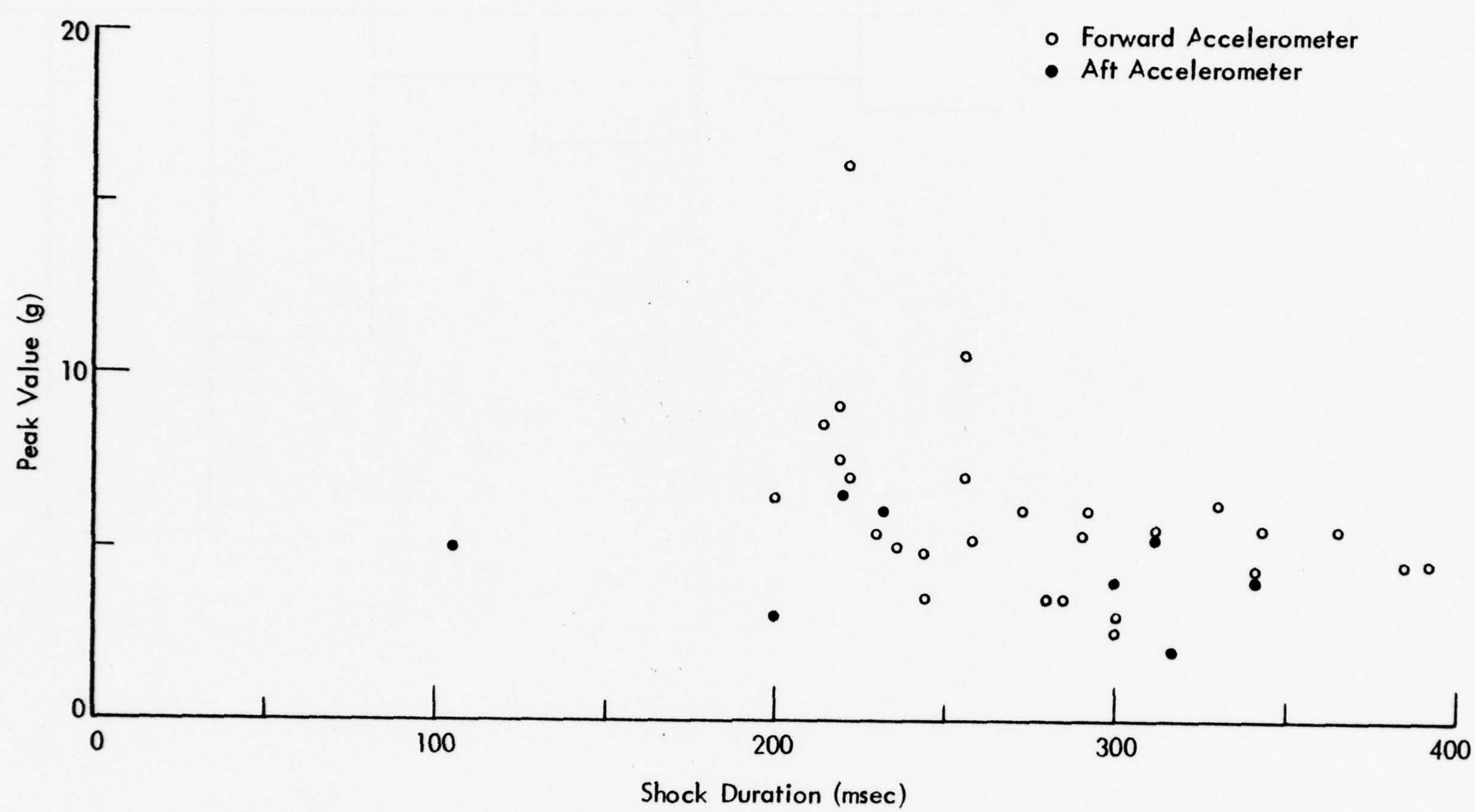


FIGURE A-9. TWENTY-ONE FT (6.4 M) SEABIRD POUNDING DATA, RUN 2

162

164

165

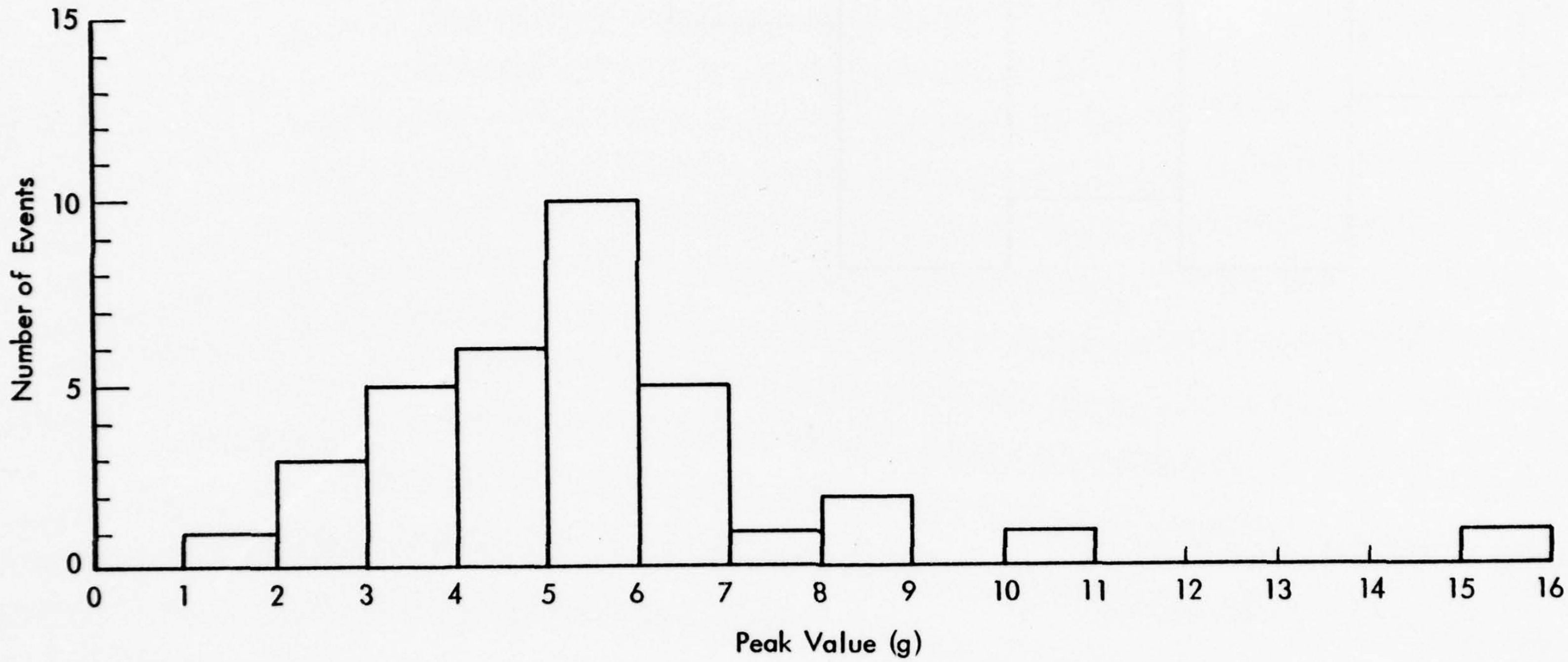


FIGURE A-10. PEAK VALUE HISTOGRAM FOR 21 FT (6.4 M) SEABIRD DATA, RUN 2

S/S 292-531 163 165

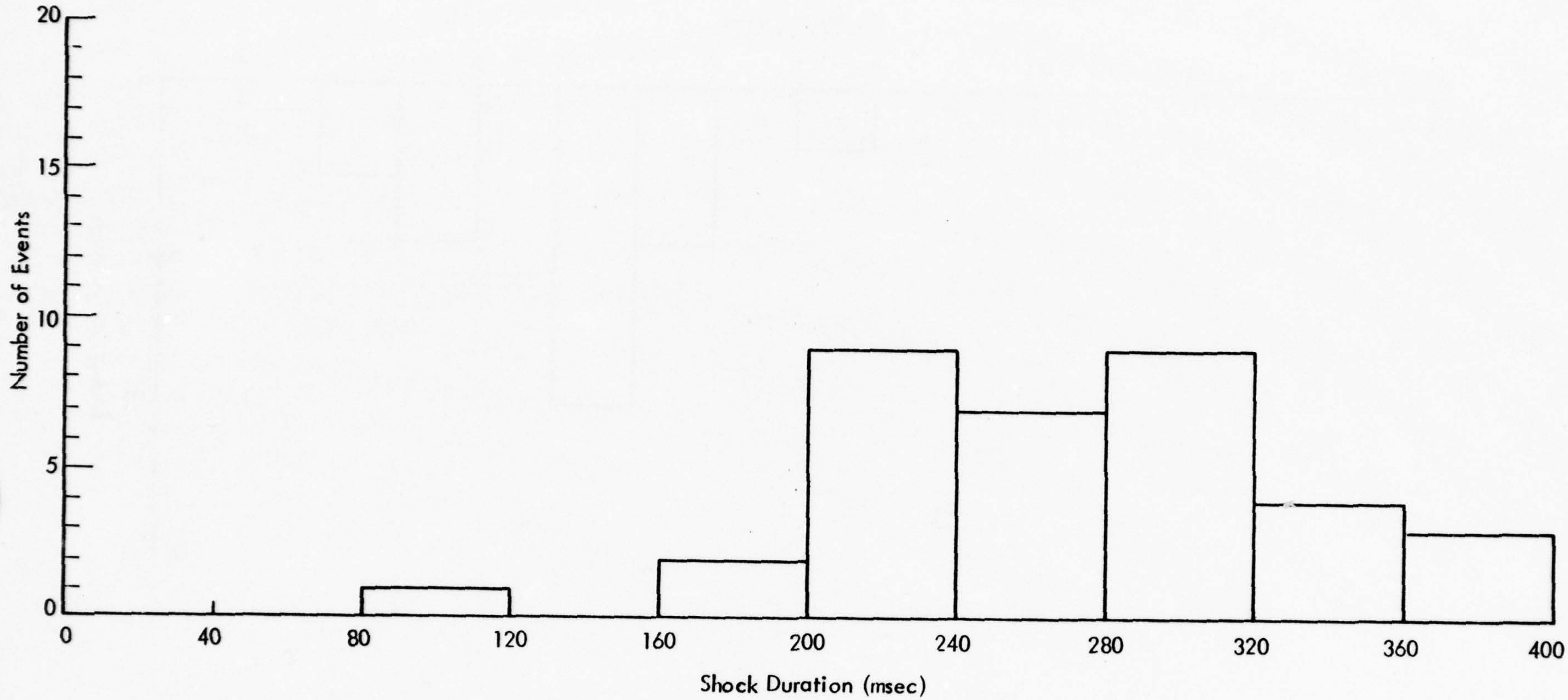


FIGURE A-11. DURATION HISTOGRAM FOR 21 FT (6.4 M) SEABIRD DATA, RUN 2

90%

292-531

(164)

(166)

(170)

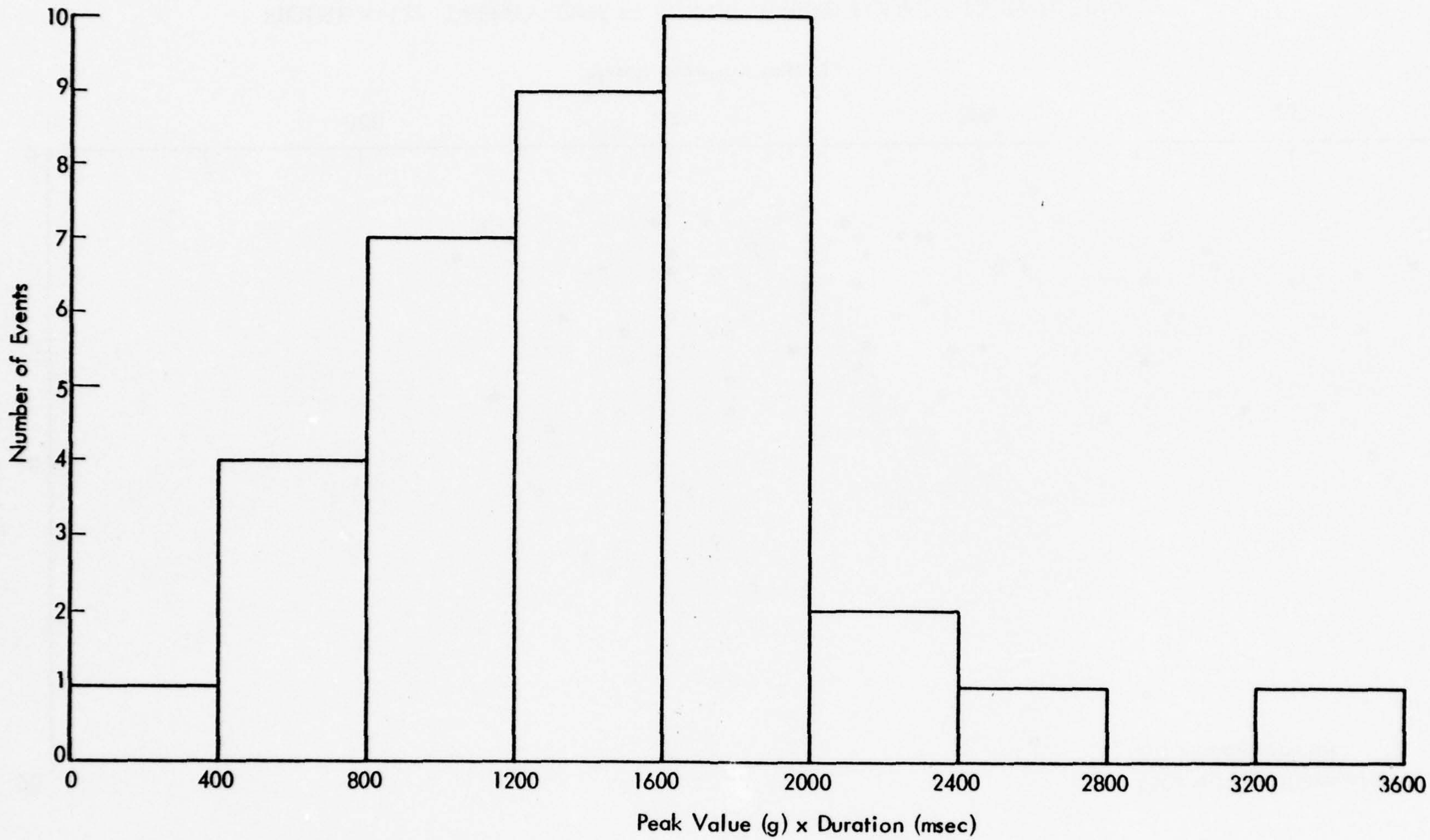


FIGURE A-12. HISTOGRAM OF PEAK VALUE X DURATION FOR 21 FT (6.4 M) SEABIRD DATA, RUN 2

S/S 292-531 165 167

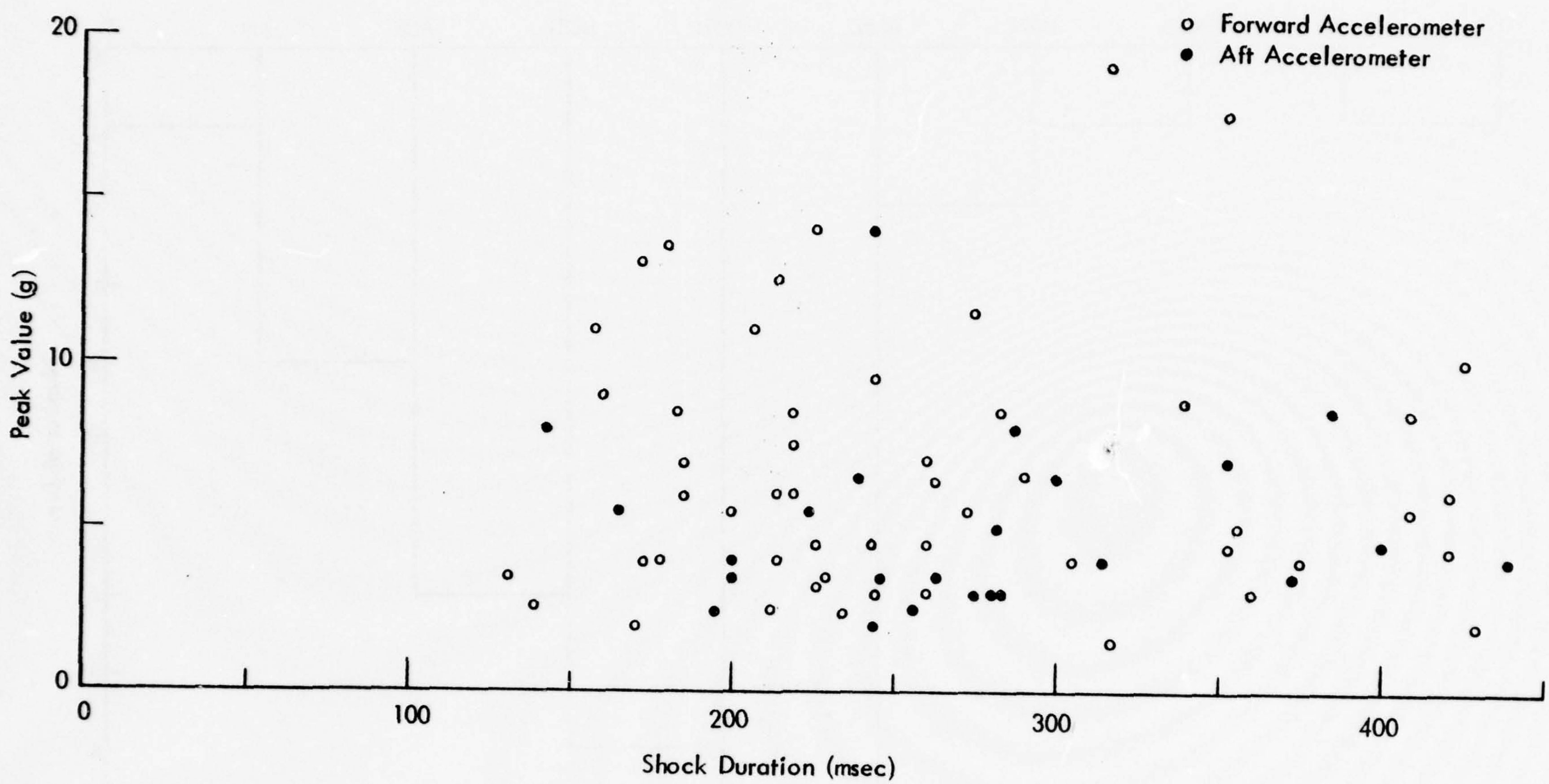


FIGURE A-13. TWENTY-ONE FT (6.4 M) SEABIRD POUNDING DATA, RUN 3

90% 292-531 166 168 172

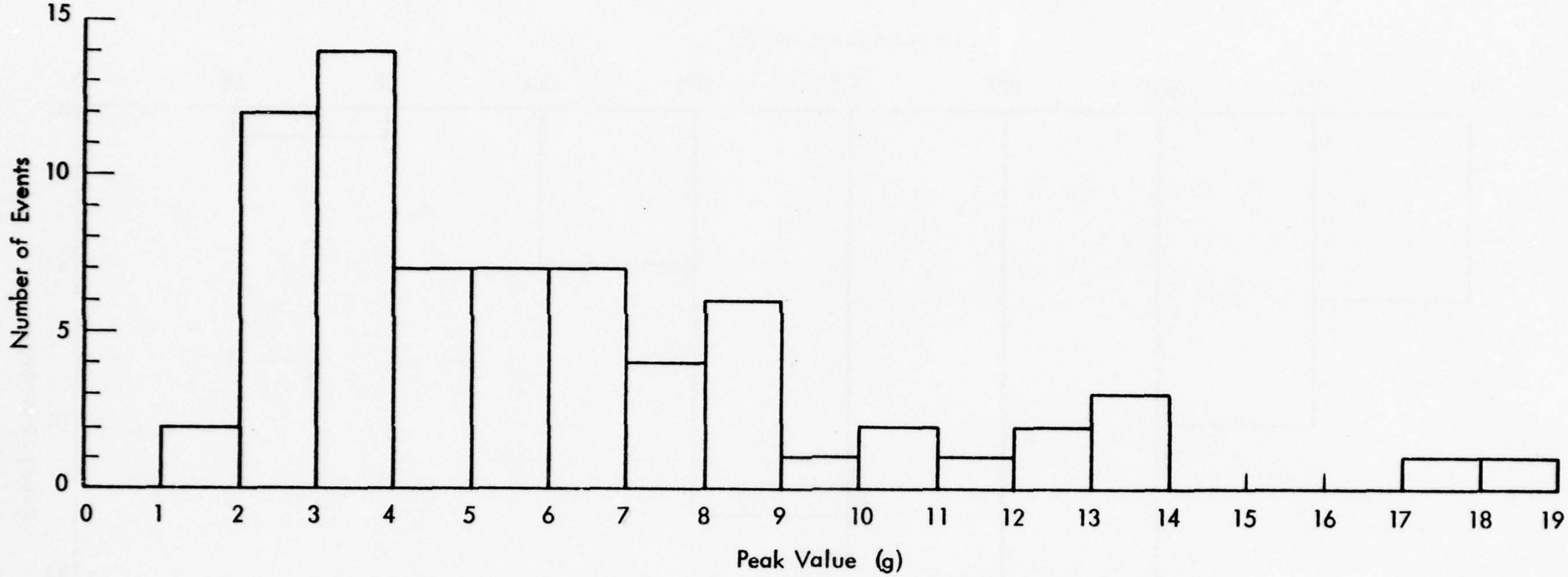


FIGURE A-14. PEAK VALUE HISTOGRAM FOR 21 FT (6.4 M) SEABIRD DATA, RUN 3

90%

292-531

167

169

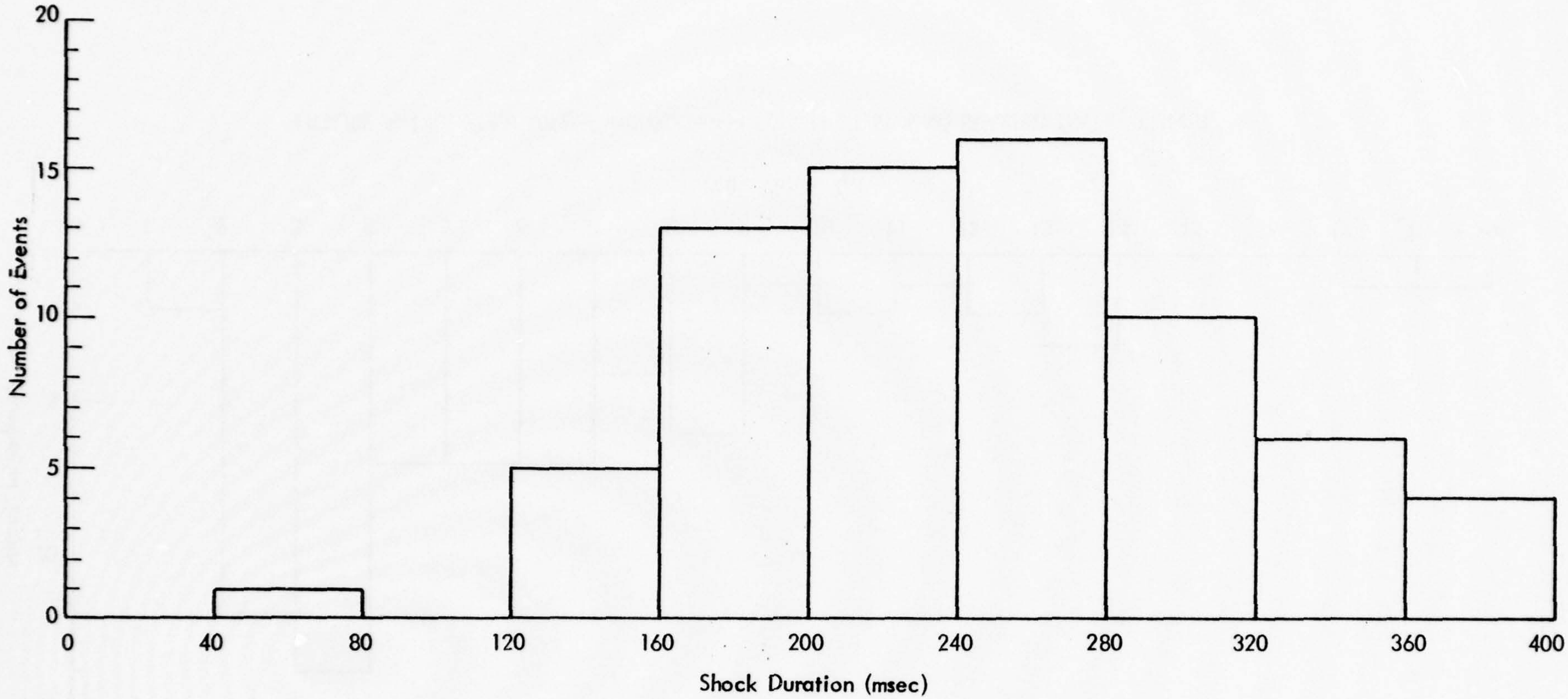


FIGURE A-15. DURATION HISTOGRAM FOR 21 FT (6.4 M) SEABIRD DATA, RUN 3

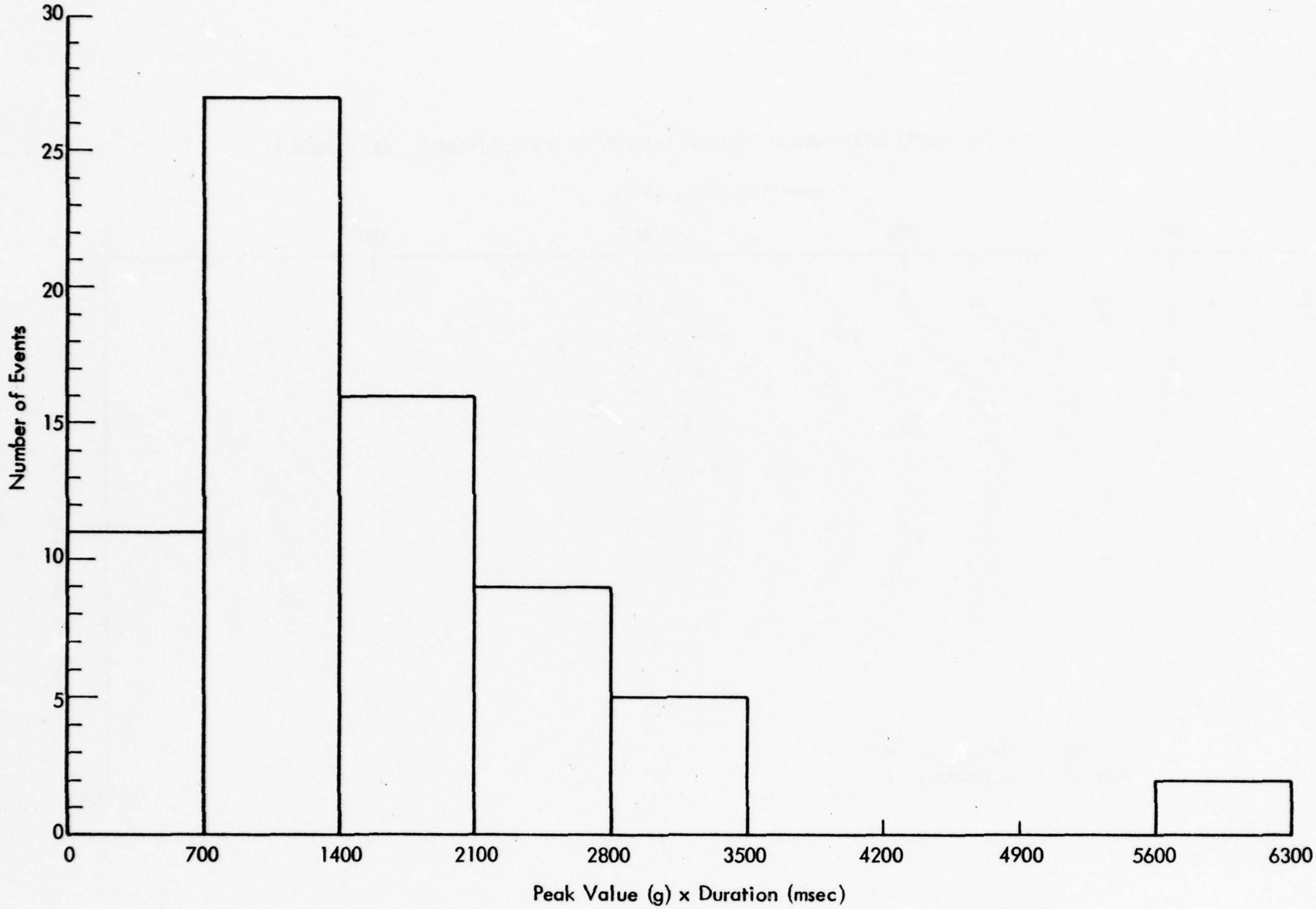


FIGURE A-16. HISTOGRAM OF PEAK VALUE X DURATION FOR 21 FT (6.4 M) SEABIRD DATA, RUN 3

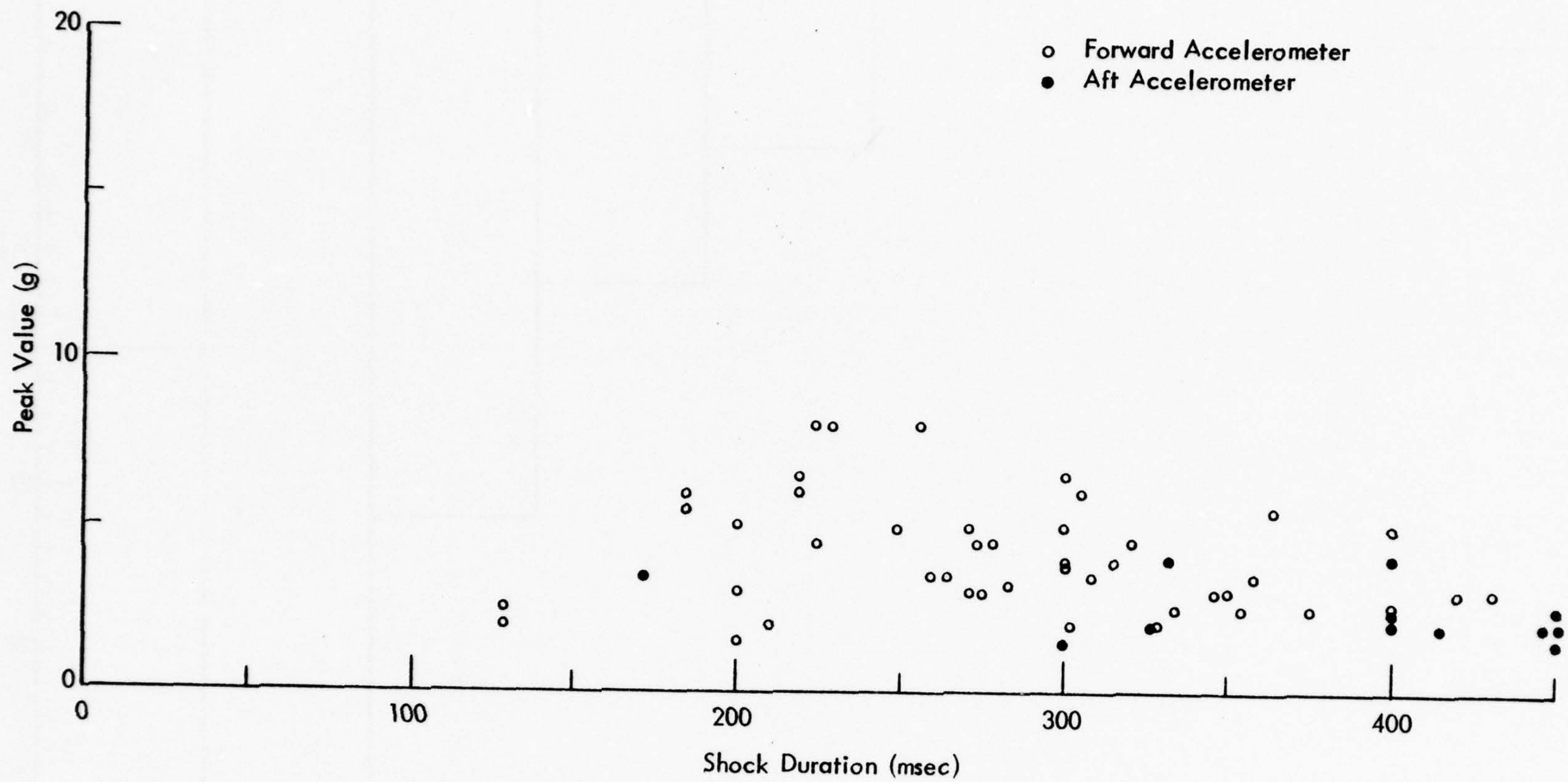


FIGURE A-17. TWENTY-ONE FT (6.4 M) SEABIRD POUNDING DATA, RUN 4

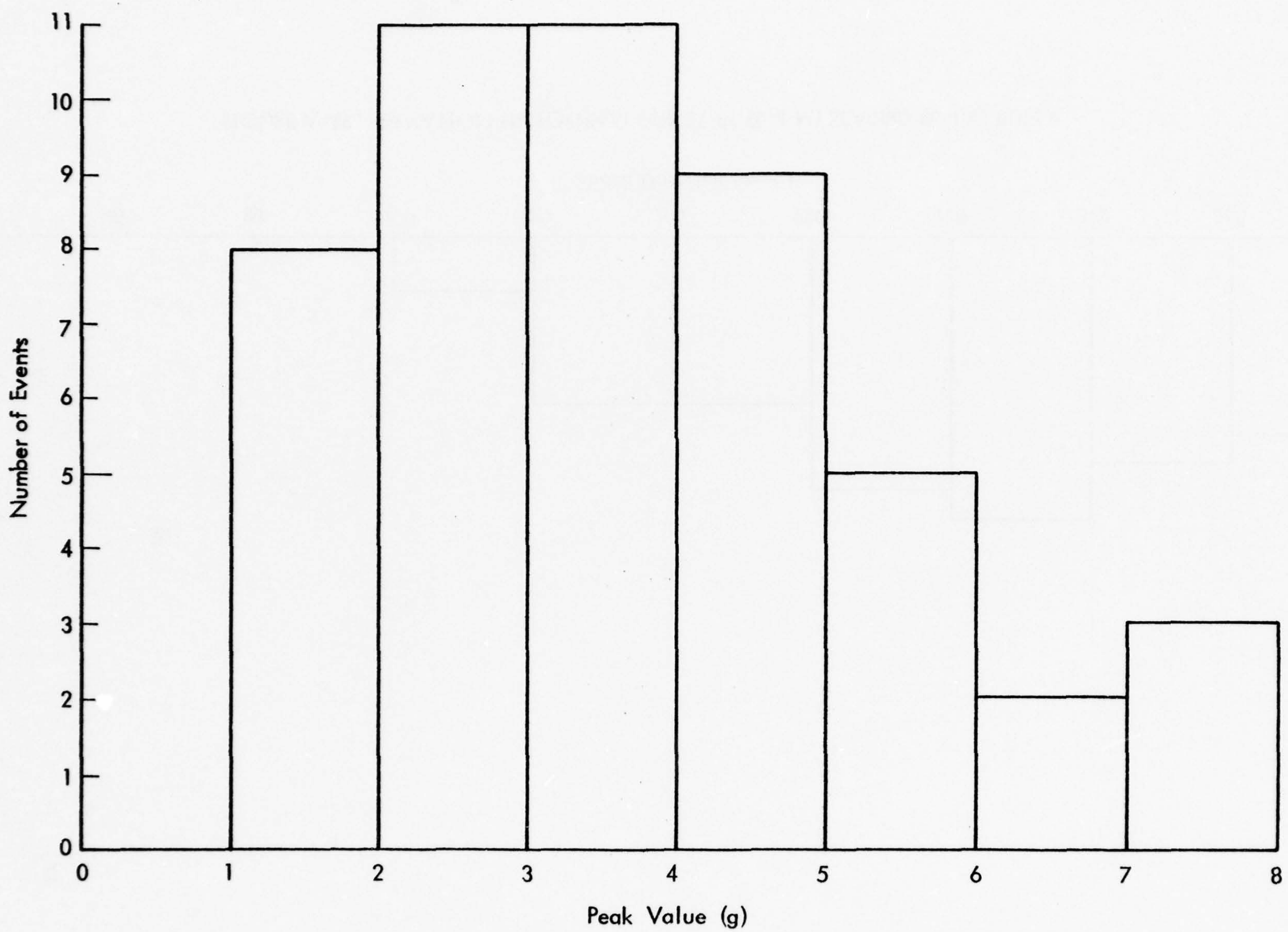


FIGURE A-18. PEAK VALUE HISTOGRAM FOR 21 FT (6.4 M) SEABIRD DATA, RUN 4

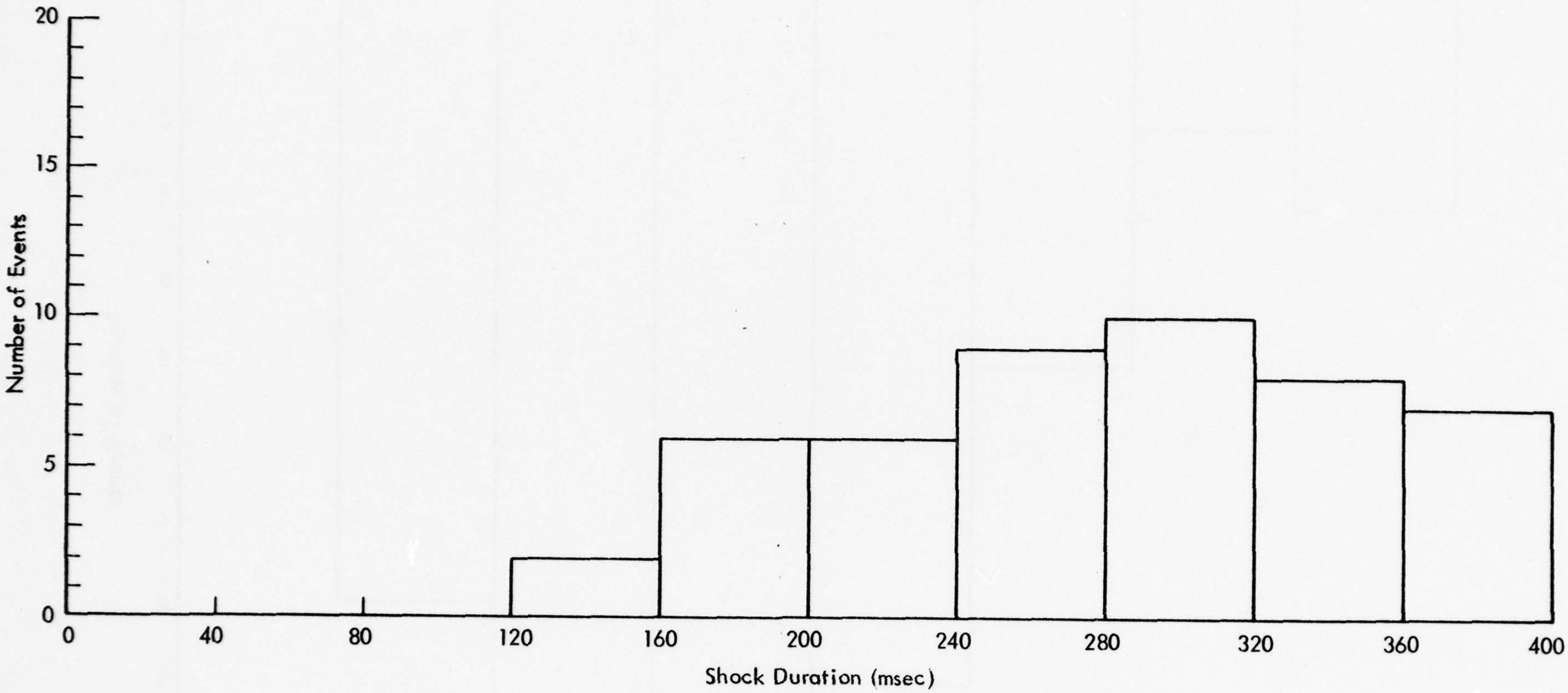


FIGURE A-19. DURATION HISTOGRAM FOR 21 FT (6.4 M) SEABIRD DATA, RUN 4

90%

292-531 172 174

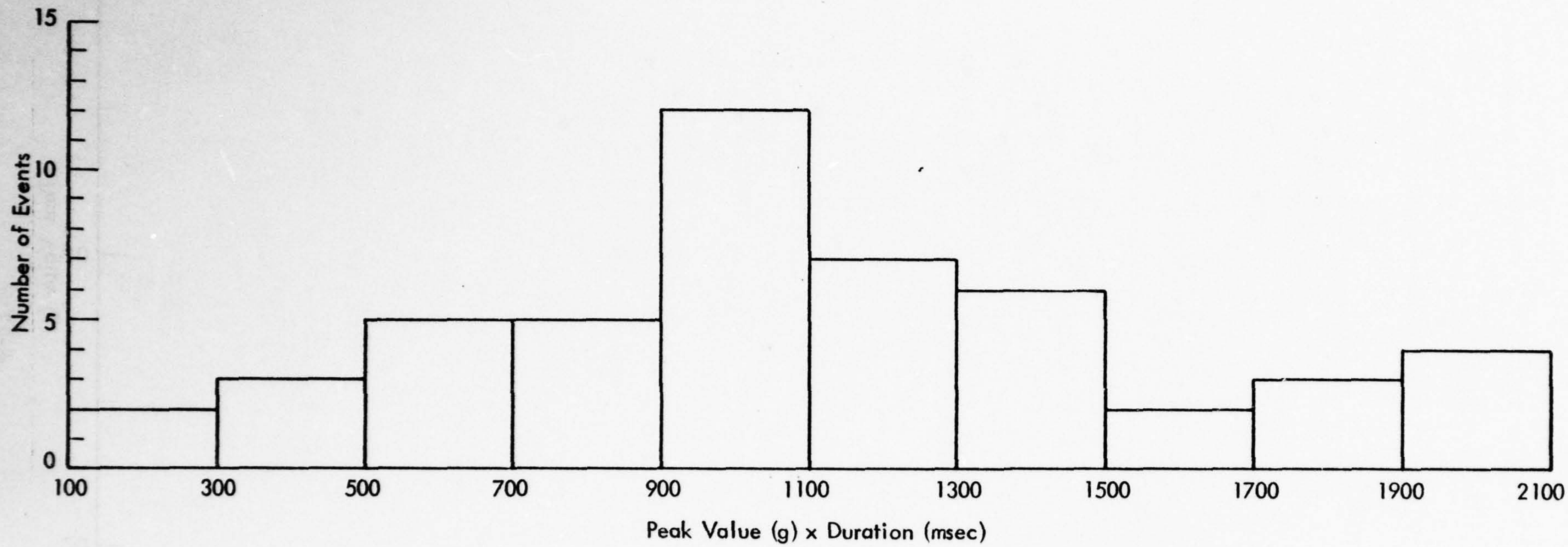


FIGURE A-20. HISTOGRAM OF PEAK VALUE X DURATION FOR 21 FT (6.4 M) SEABIRD DATA, RUN 4

(173)

(175)

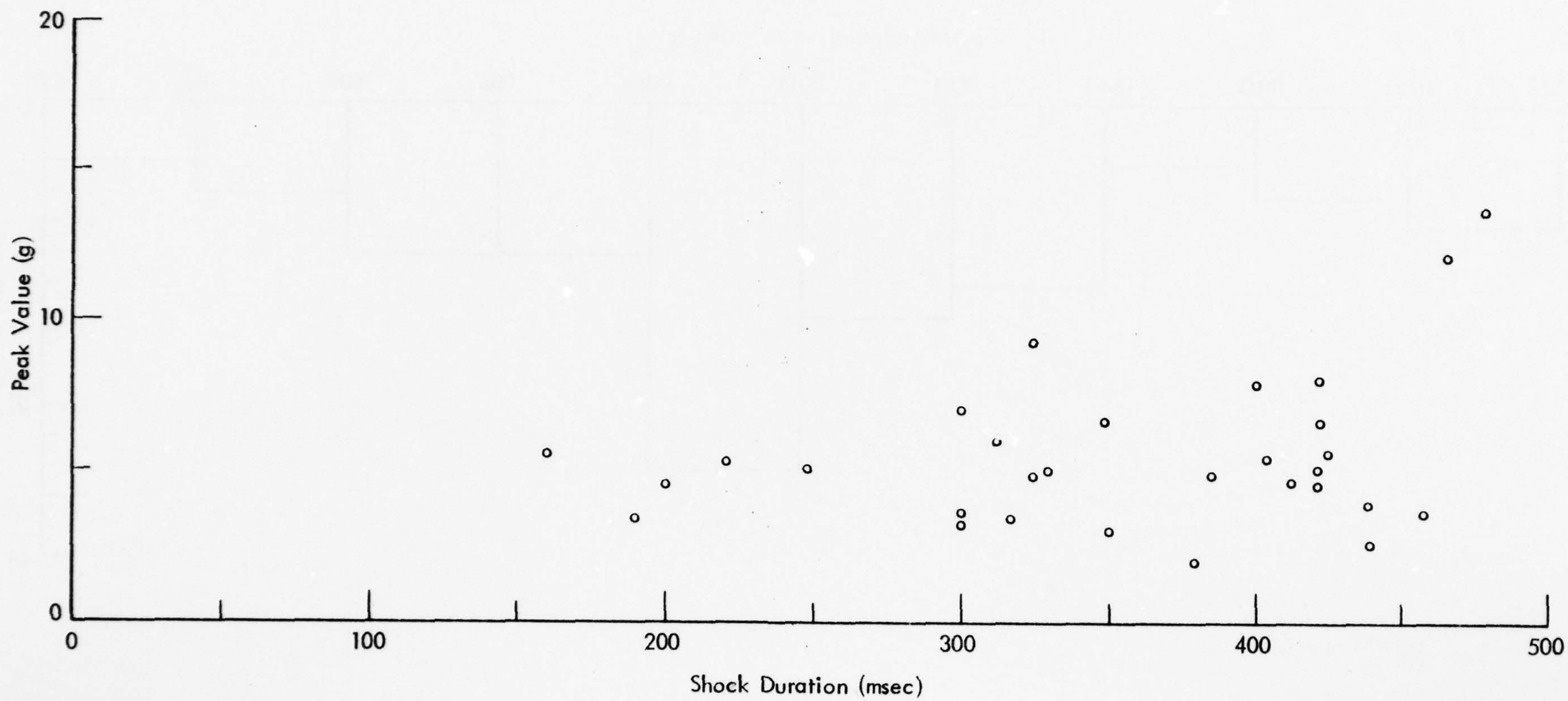


FIGURE A-21. FIFTEEN FT (4.6 M) GLASTRON SWINGER DATA, FORWARD ACCELEROMETER

90%

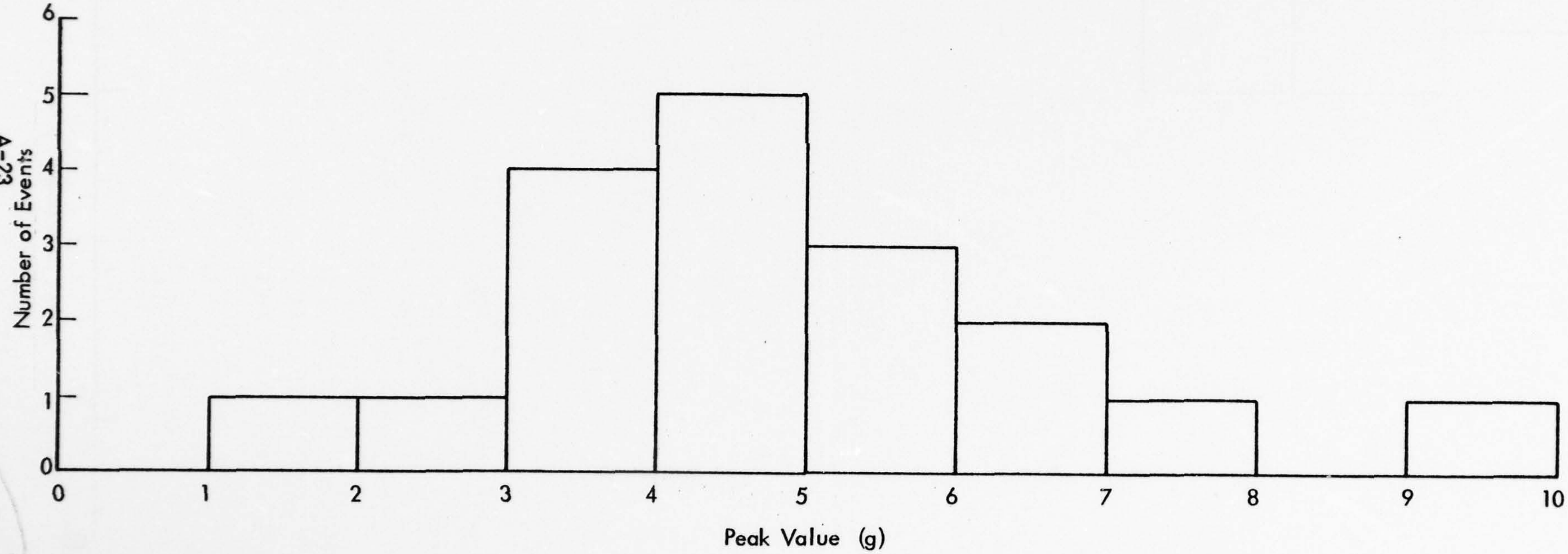


FIGURE A-22. PEAK VALUE HISTOGRAM FOR 15 FT (4.6 M) GLASTRON SWINGER DATA

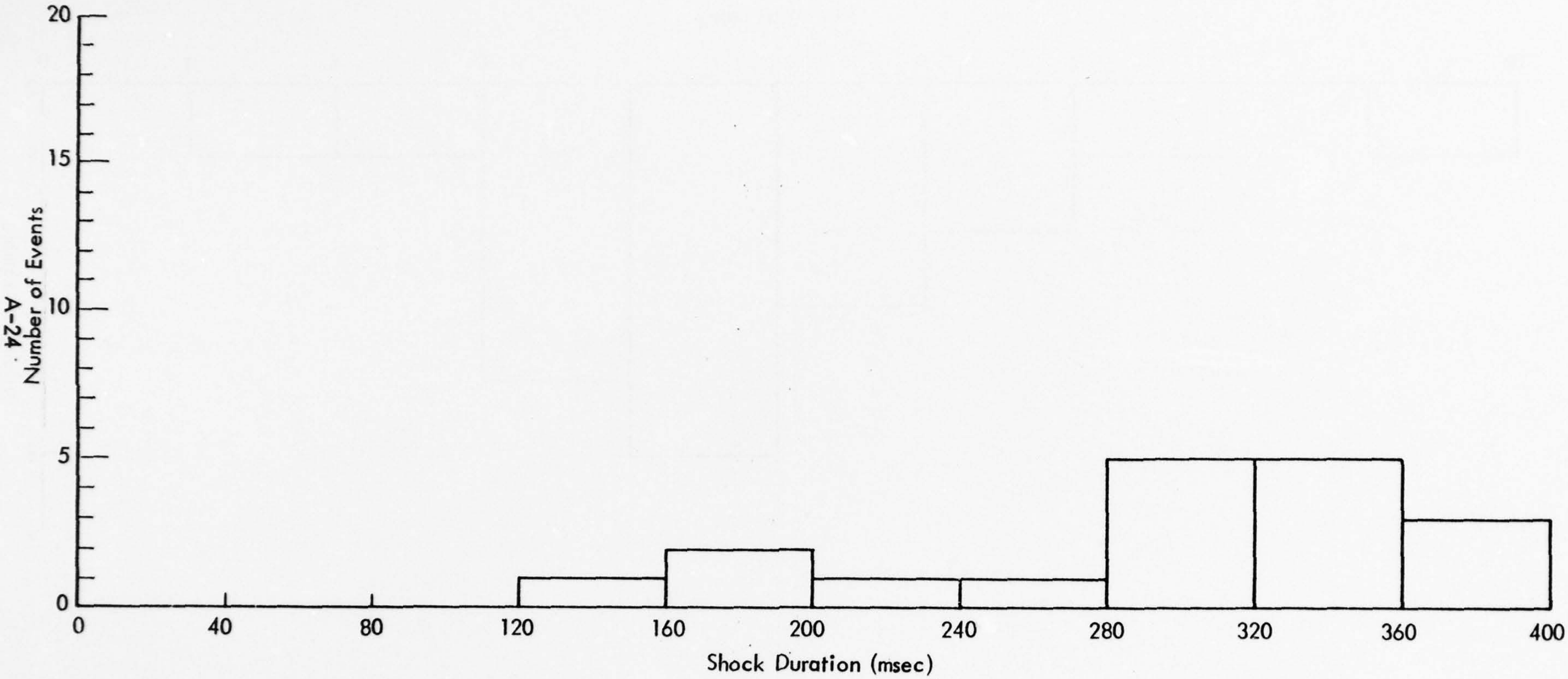


FIGURE A-23. DURATION HISTOGRAM FOR 15 FT (4.6 M) GLASTRON SWINGER DATA

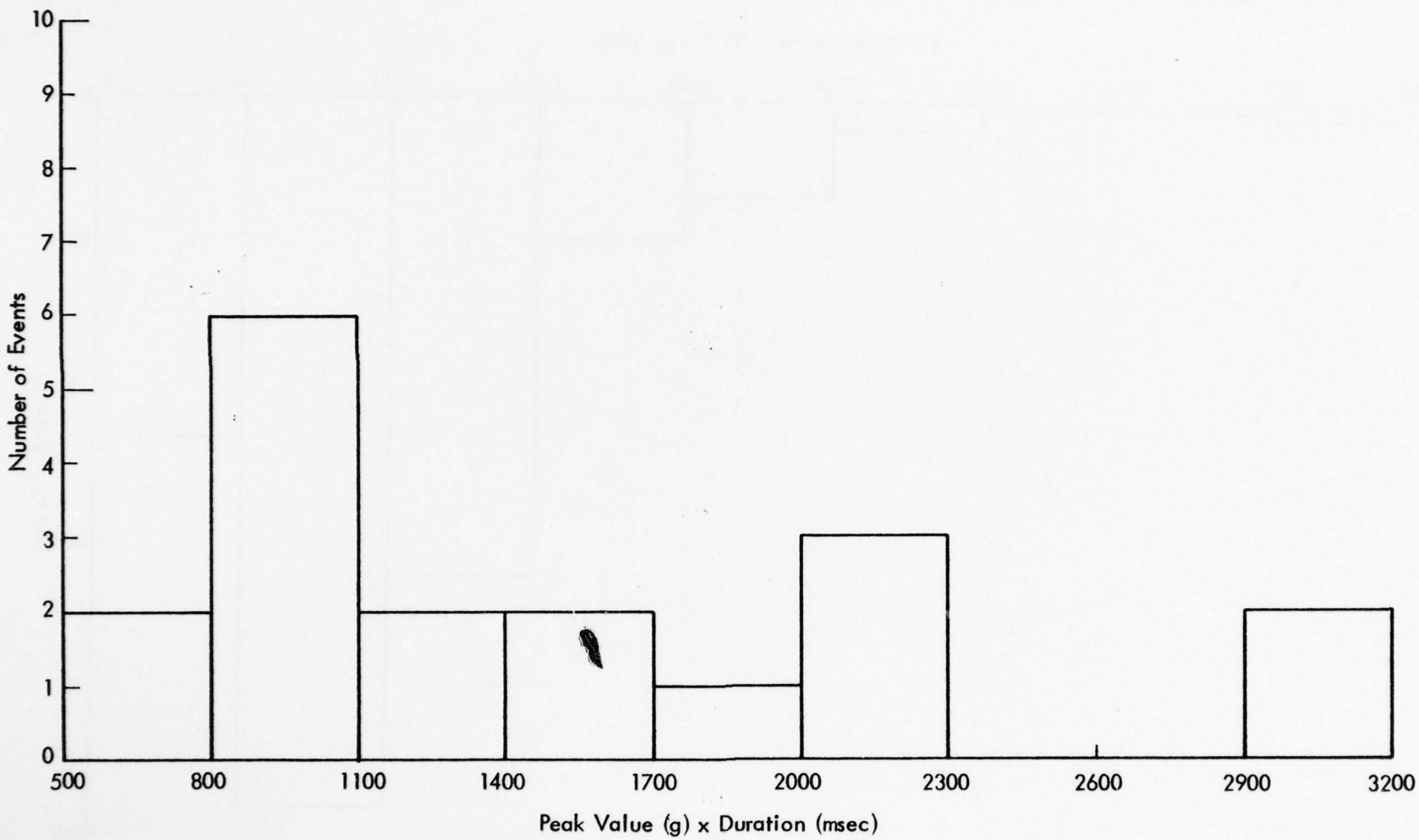


FIGURE A-24. HISTOGRAM OF PEAK VALUE X DURATION FOR 15 FT (4.6 M) GLASTRON SWINGER DATA

177

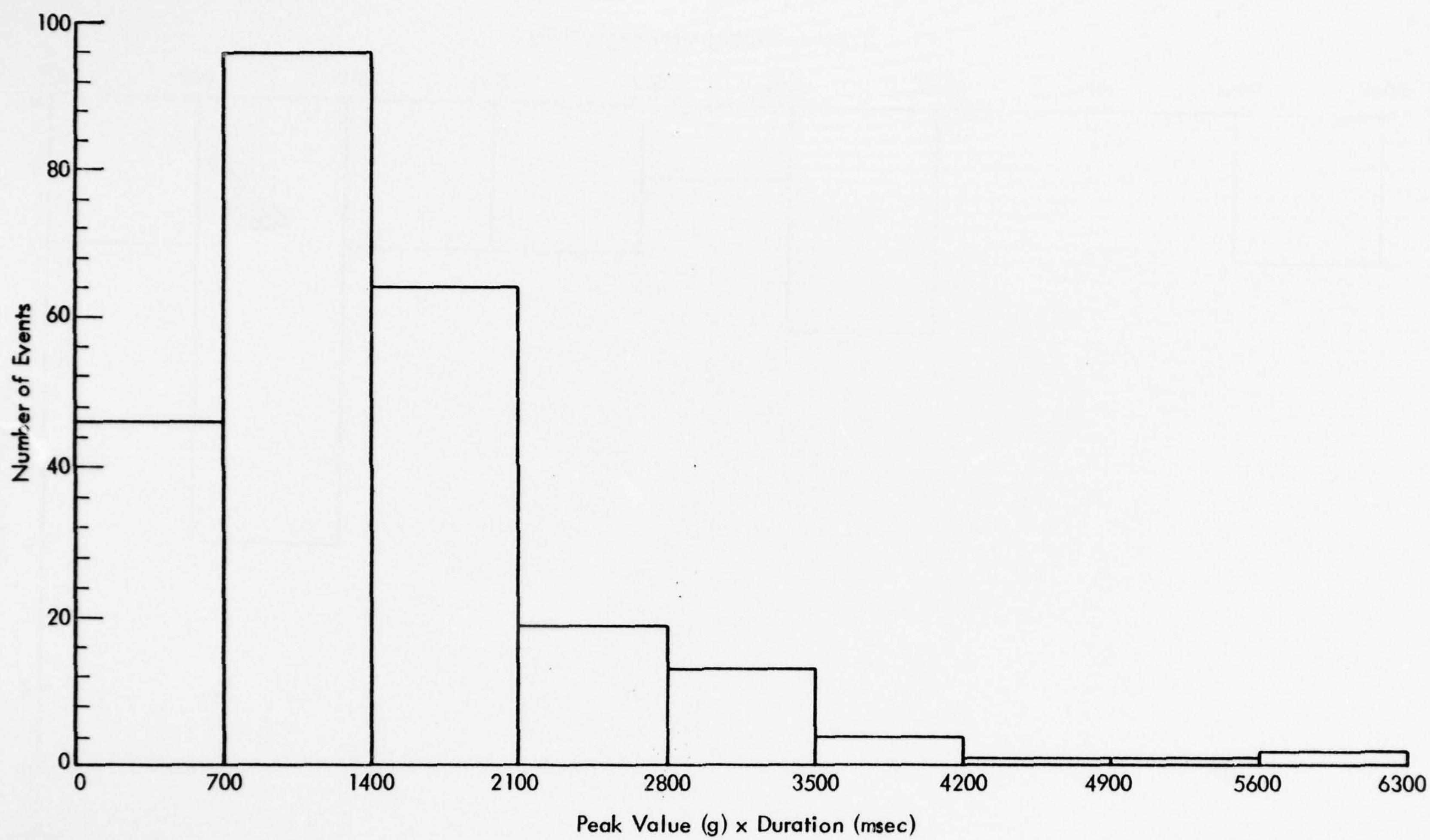


FIGURE A-25. HISTOGRAM OF PEAK VALUE X DURATION FOR COMBINED STAMAS, SEABIRD AND GLASTRON DATA

292-531

178

180

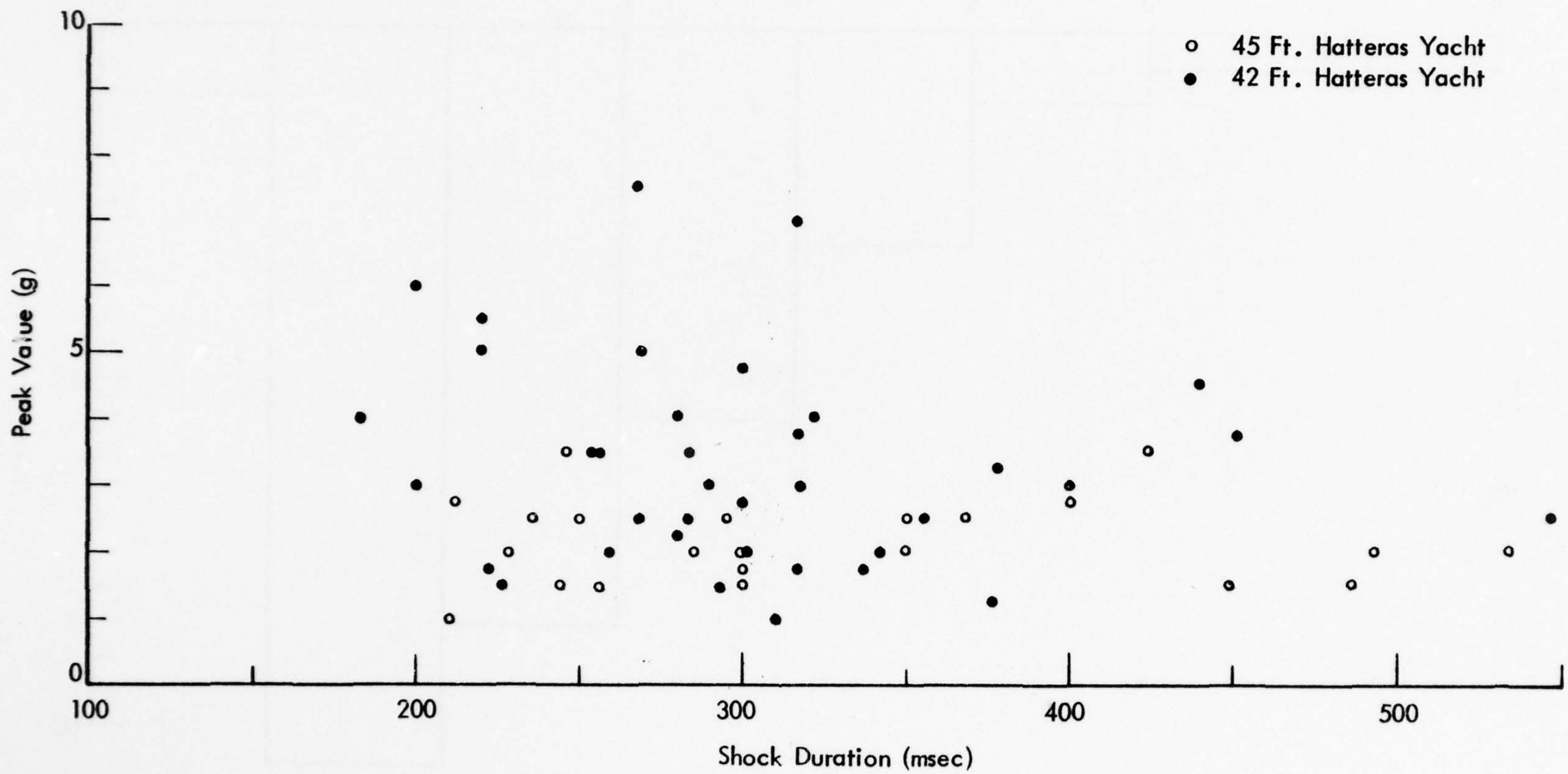


FIGURE A-26. POUNDING DATA FOR 42 FT (12.8 M) AND 45 FT (13.7 M) HATTERAS YACHTS

179

181

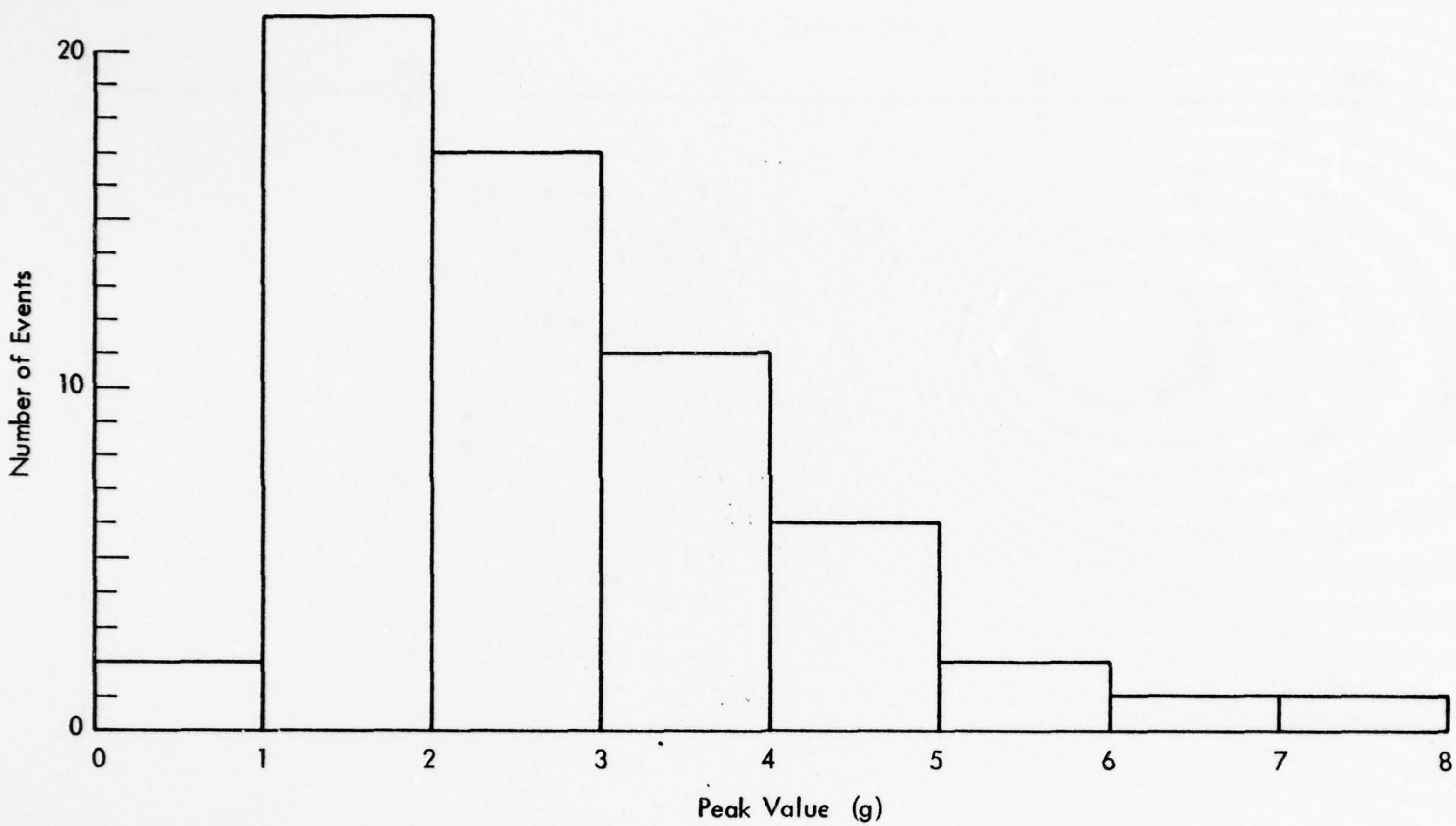


FIGURE A-27. PEAK VALUE HISTOGRAM FOR 42 FT (12.8 M) AND 45 FT (13.7 M) HATTERAS YACHT DATA

180

182

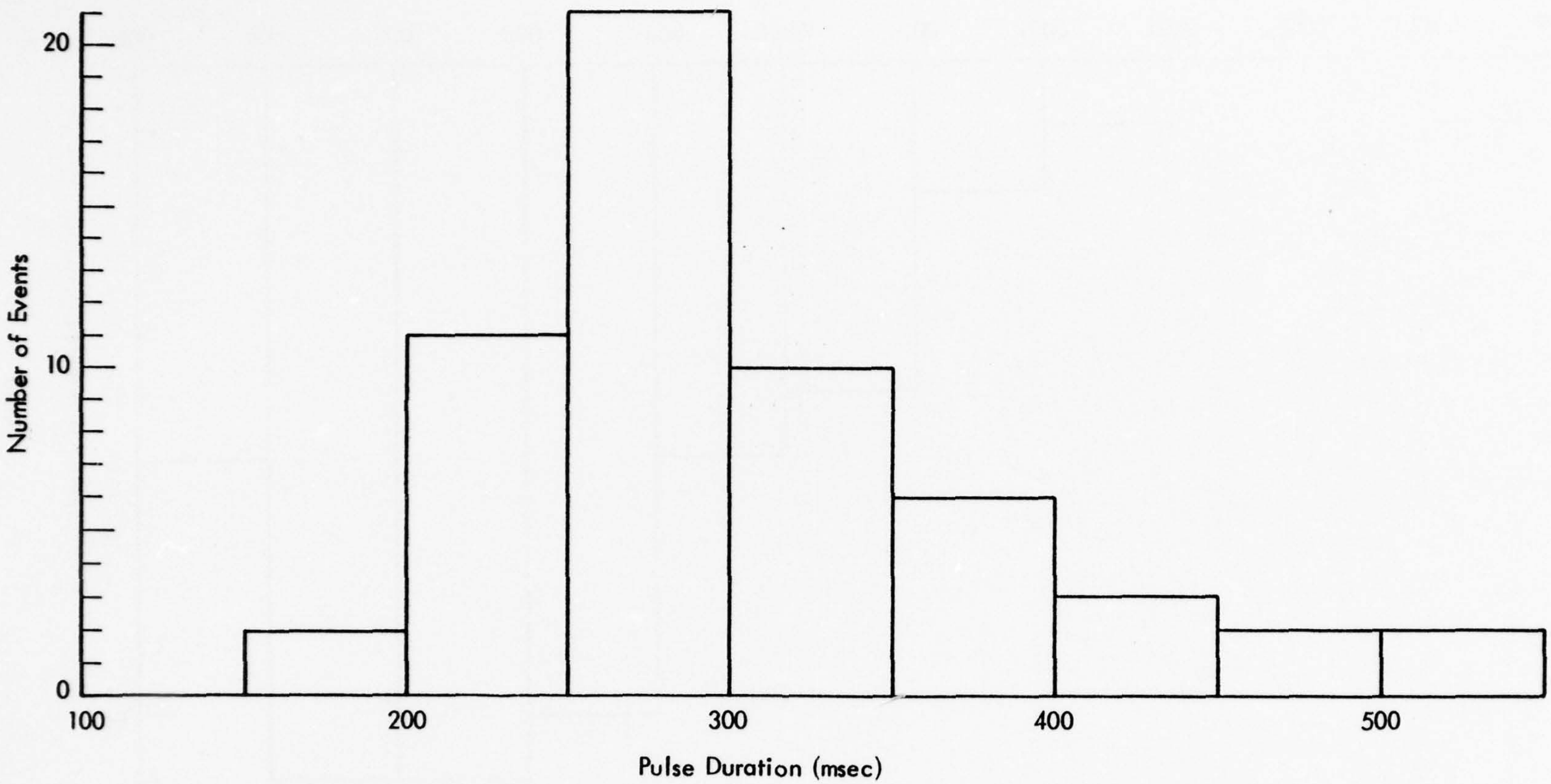


FIGURE A-28. DURATION HISTOGRAM FOR 42 FT (12.8 M) AND 45 FT (13.7 M) HATTERAS YACHT DATA

292-531

181

183

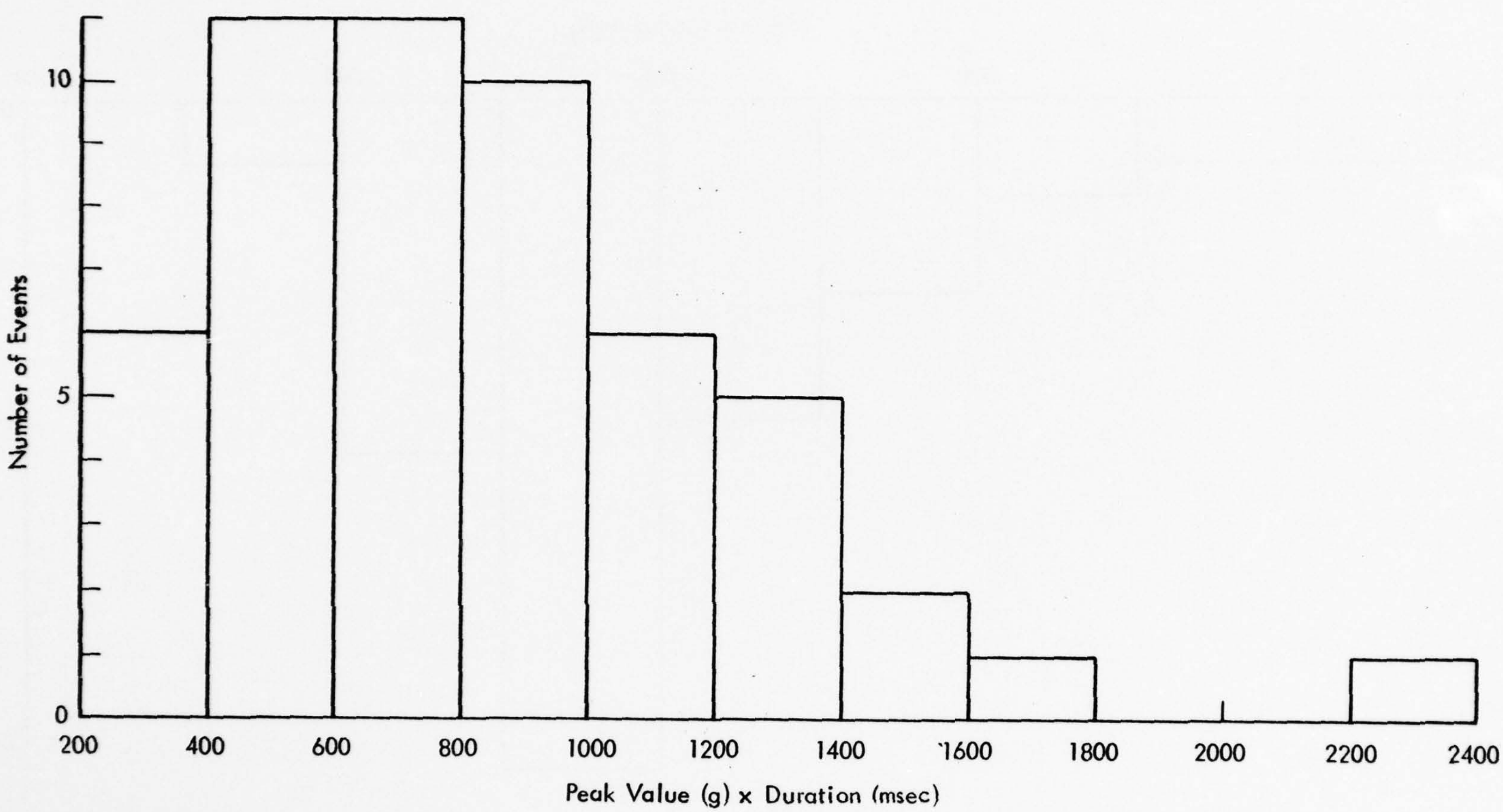


FIGURE A-29. HISTOGRAM OF PEAK VALUE X DURATION FOR 42 FT (12.8 M) AND 45 FT (13.7 M) HATTERAS YACHT DATA

292-531

182

184

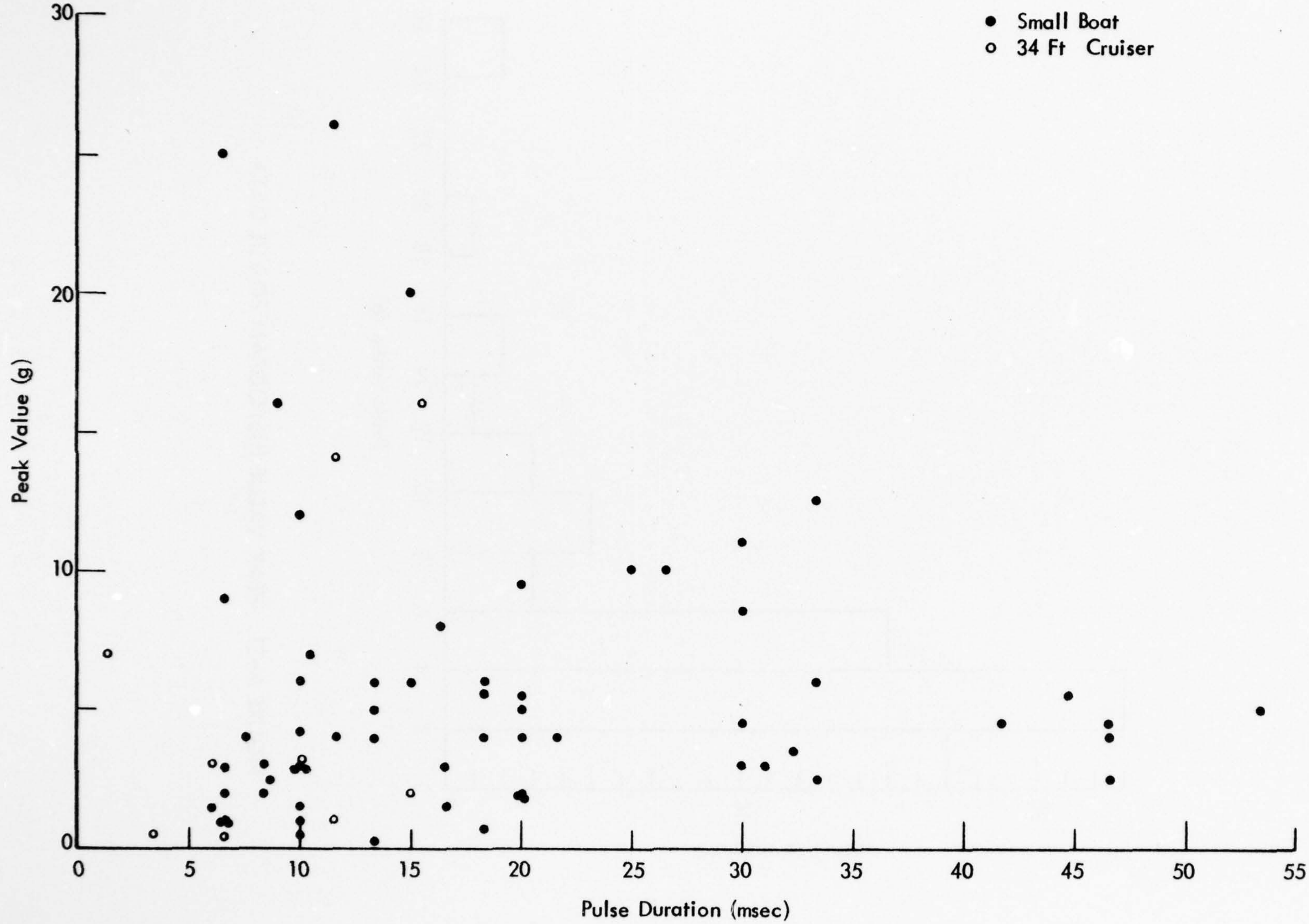


FIGURE A-30. UL POUNDING DATA

183

185

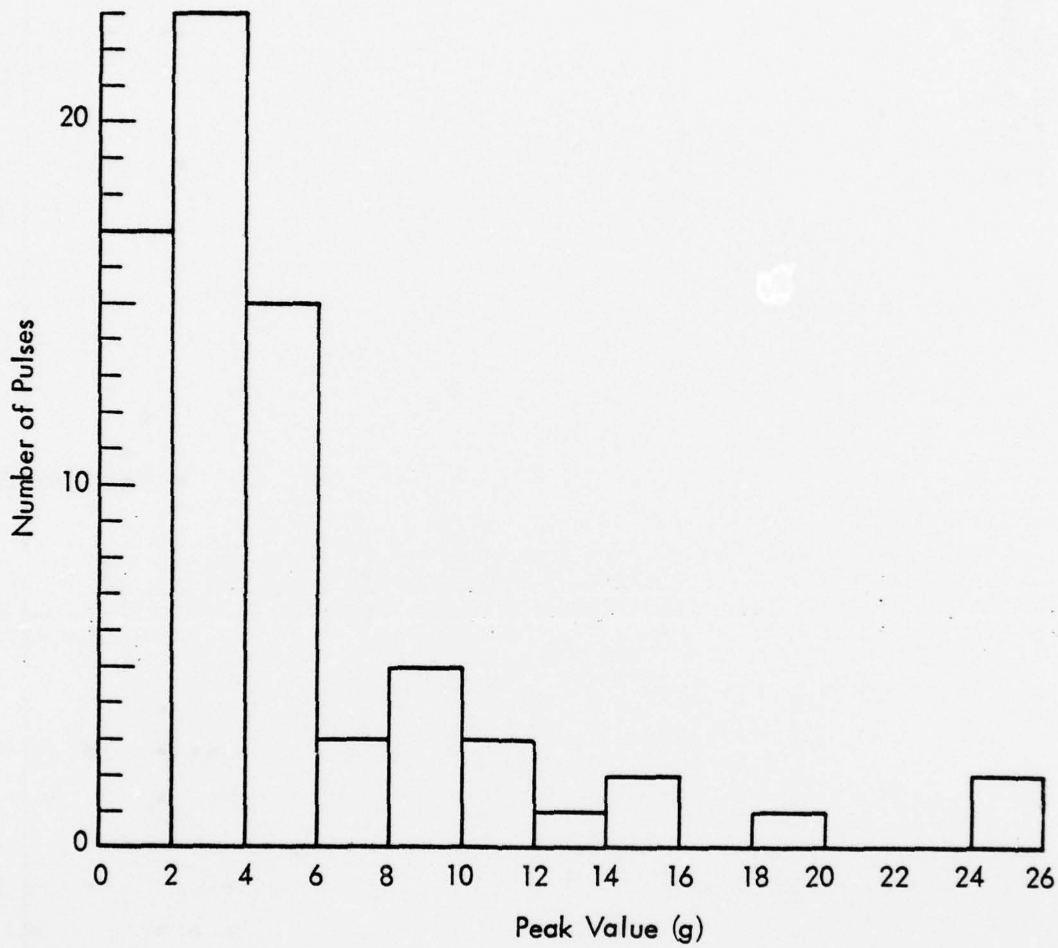


FIGURE A-31. PEAK VALUE HISTOGRAM FOR UL DATA

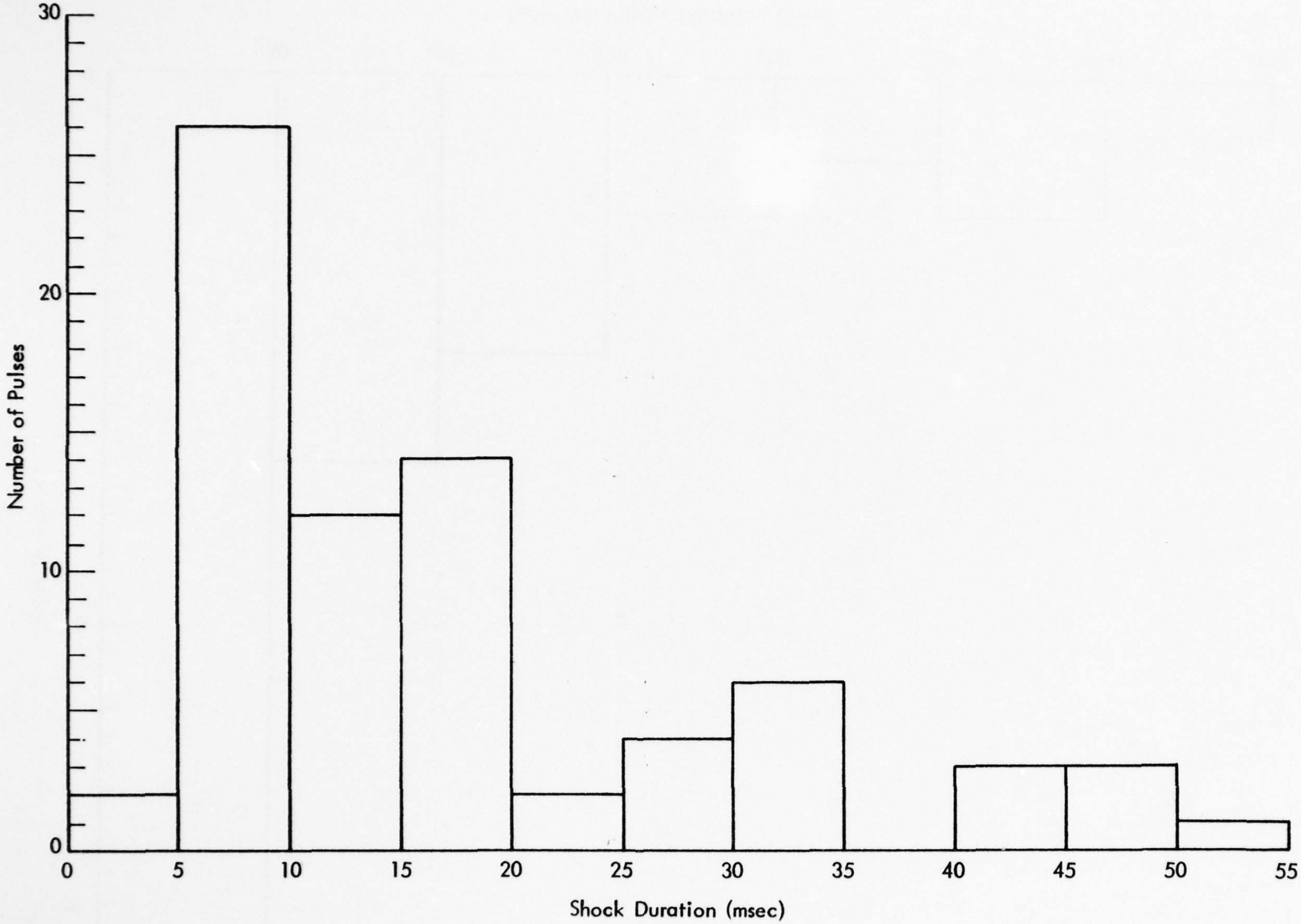


FIGURE A-32. DURATION HISTOGRAM FOR UL DATA

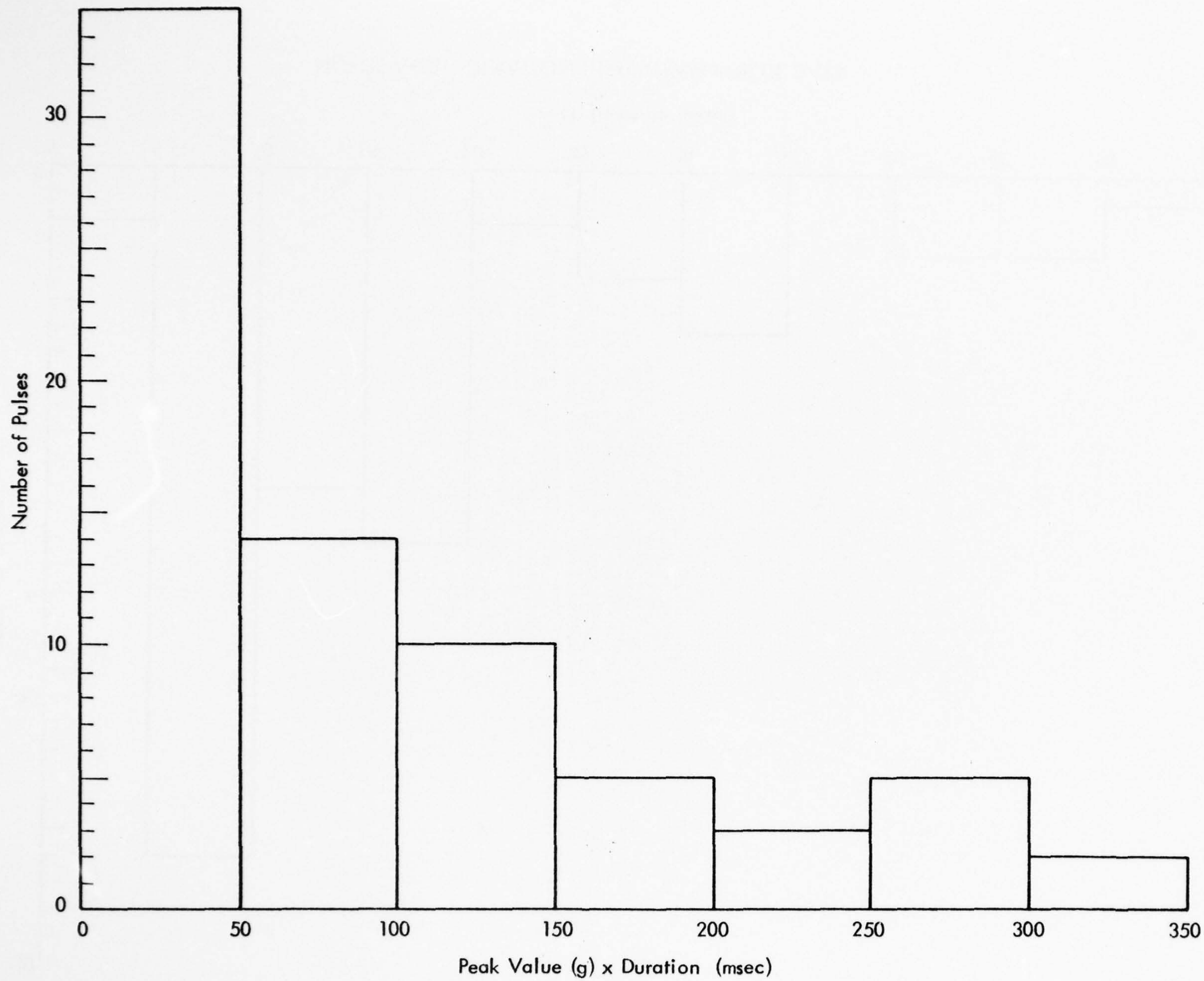


FIGURE A-33. HISTOGRAM OF PEAK VALUE X DURATION FOR UL DATA

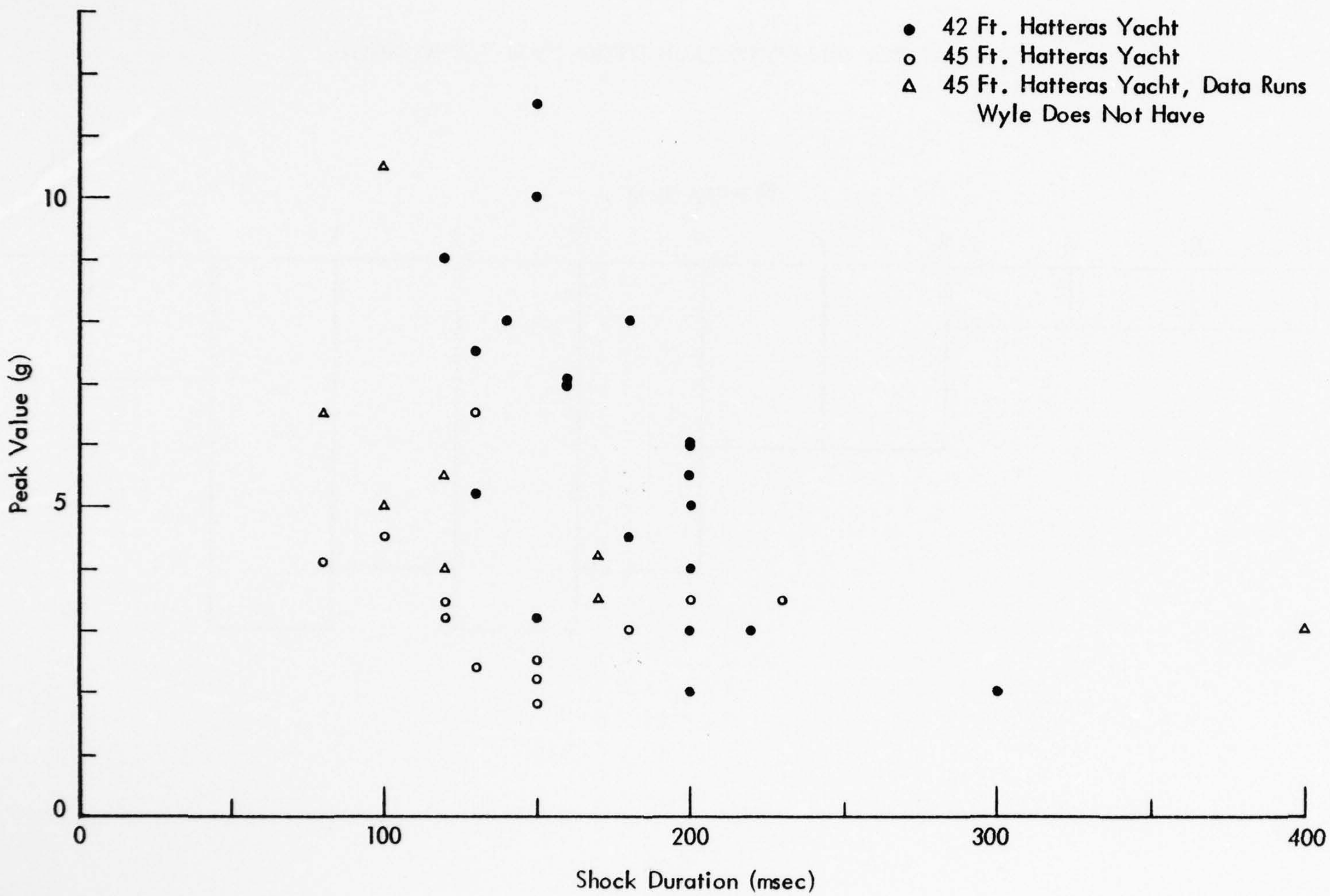


FIGURE A-34. AMF BOW SHOCK DATA

5/5

292-531

187

189

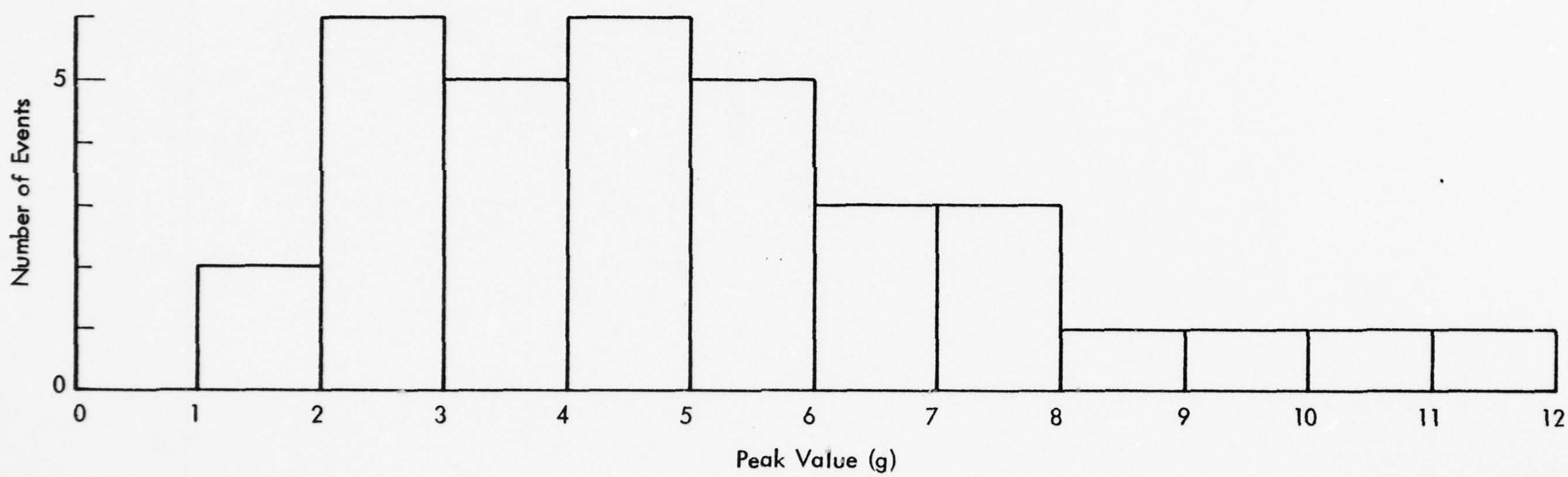


FIGURE A-35. PEAK VALUE HISTOGRAM FOR AMF DATA

90%

292-531

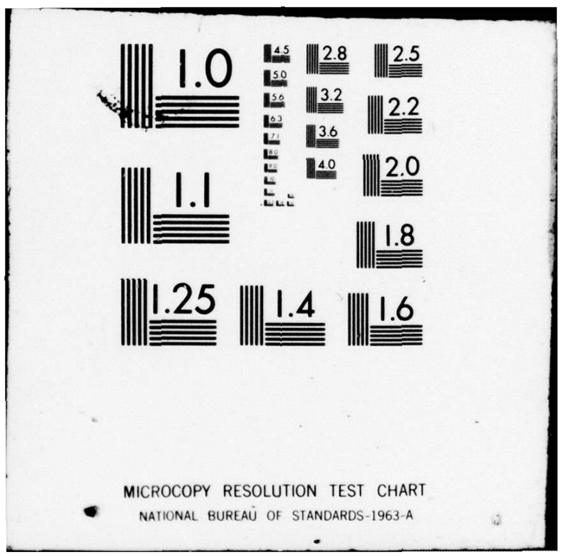
188

190

AD-A071 840 WYLE LABS HUNTSVILLE ALA F/G 13/10
DEFINITION AND CLASSIFICATION OF NATURAL AND INDUCED ENVIRONMEN--ETC(U)
SEP 78 DOT-CG-40672-A
UNCLASSIFIED WSR-78-12 USCG-D-20-79 NL

3 OF 3
AD
A071840

END
DATE
FILMED
8-79
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

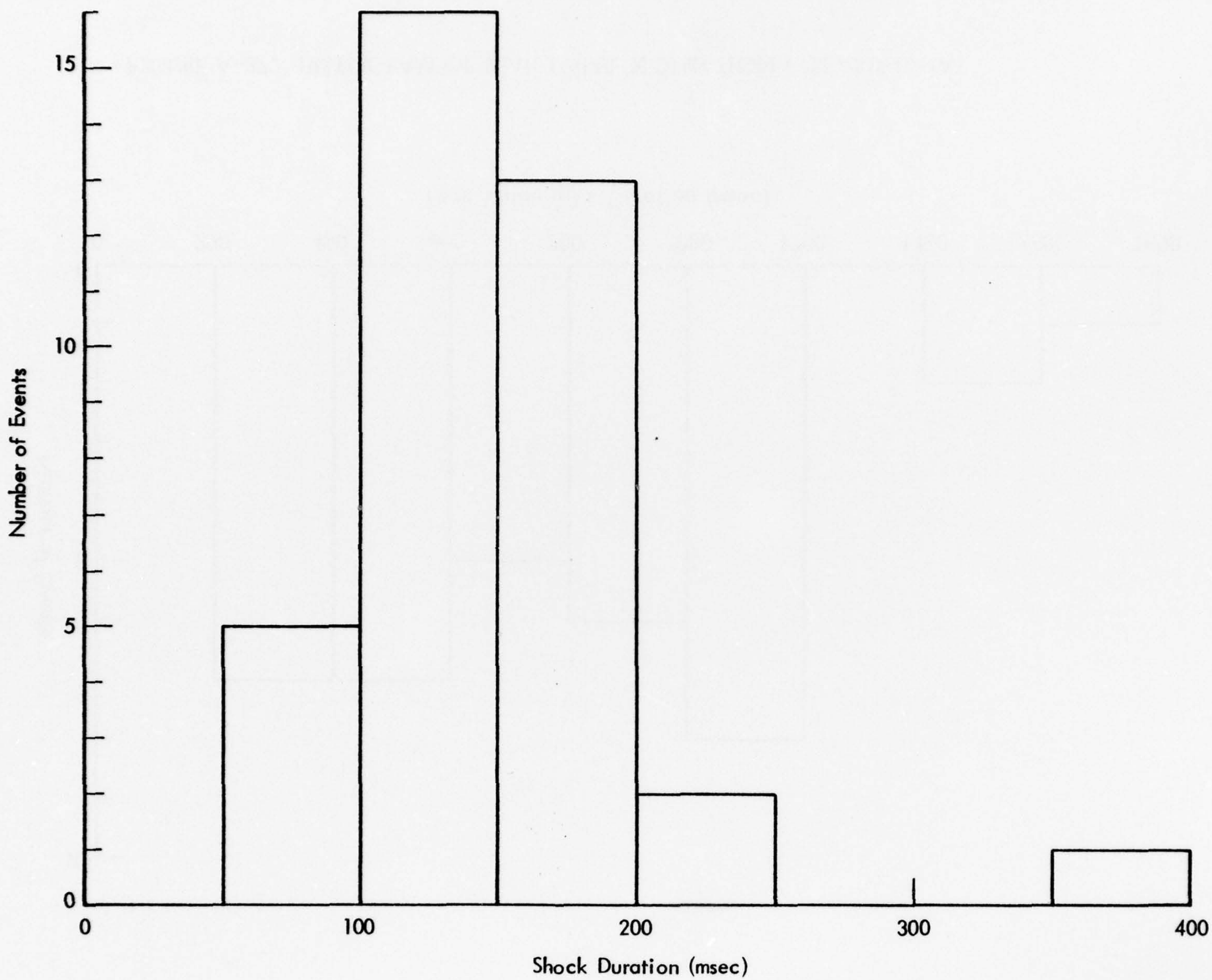


FIGURE A-36. DURATION HISTOGRAM FOR AMF DATA

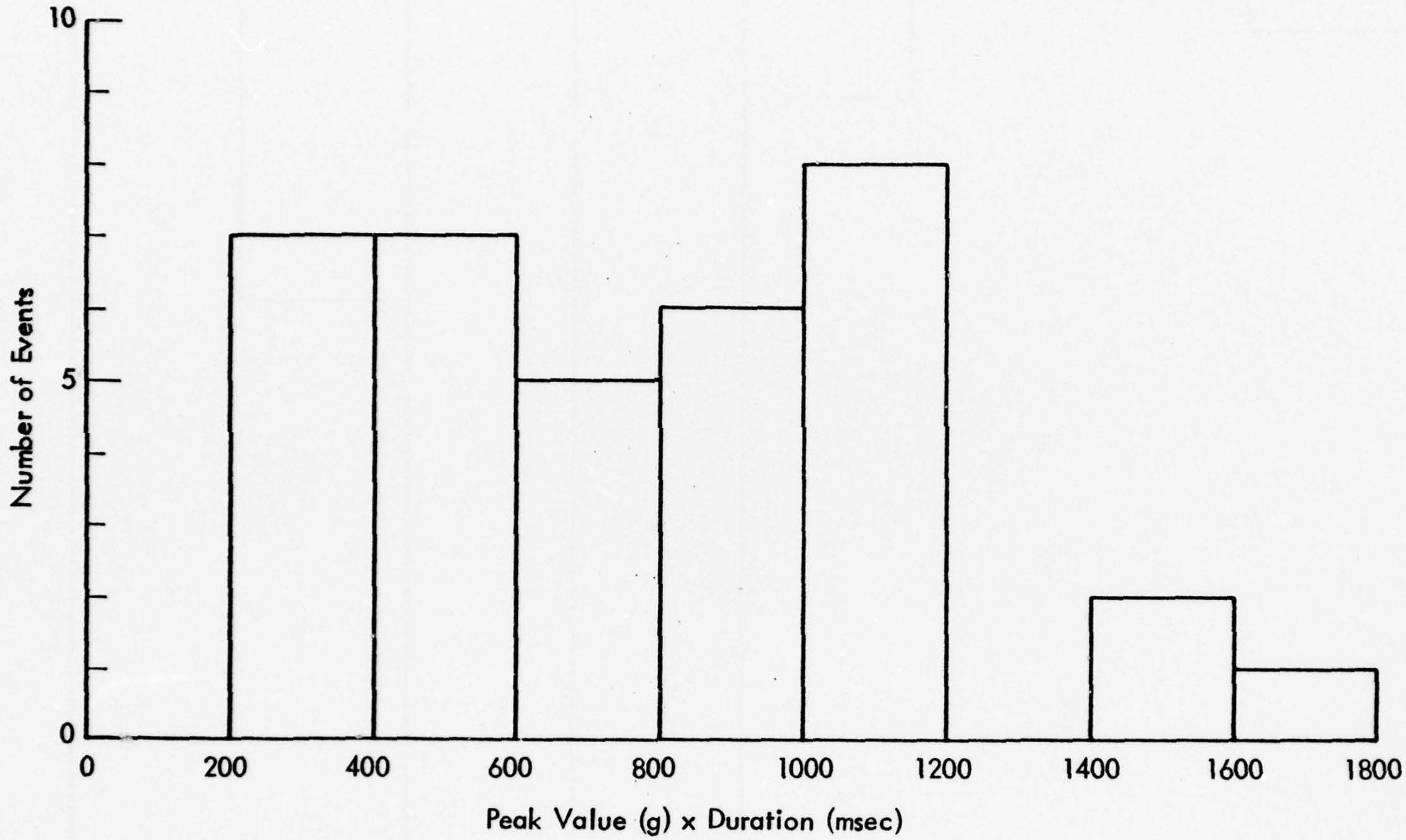


FIGURE A-37. HISTOGRAM OF PEAK VALUE X DURATION FOR AMF DATA

APPENDIX B — REDUCED DATA FOR 1975

This appendix contains data sheets derived from the data retrieved in October, 1975, using the 18 ft (5.5 m) inboard/outdrive test boat. Section IV, Paragraphs 4.0 through 10.0 provide discussion of the instrumentation types, locations, data reduction and analysis.

The data were derived from two channels (5 and 6) taken in seven runs (1, 2, 3, 4, 6, 7, and 8). Channel No. 5 was always located in the same position in the aft position next to motor mounts and channel No. 6 was moved to one of four locations as shown in Figure B-1.

Table B-1 identifies the number of the test run, the location of channels 5 and 6, the speed and rpm of the boat, and general water conditions that prevailed during each run.

There are 82 data sheets contained herein that constitute the record of 1975 data (see Figure B-2). These are as follow:

- Level Analysis - Pages B-5 through B-11
- Shock Signature - Pages B-12 through B-55
- Shock Analysis - Pages B-56 through B-83
- Power Spectral Density - Pages B-84 through B-86

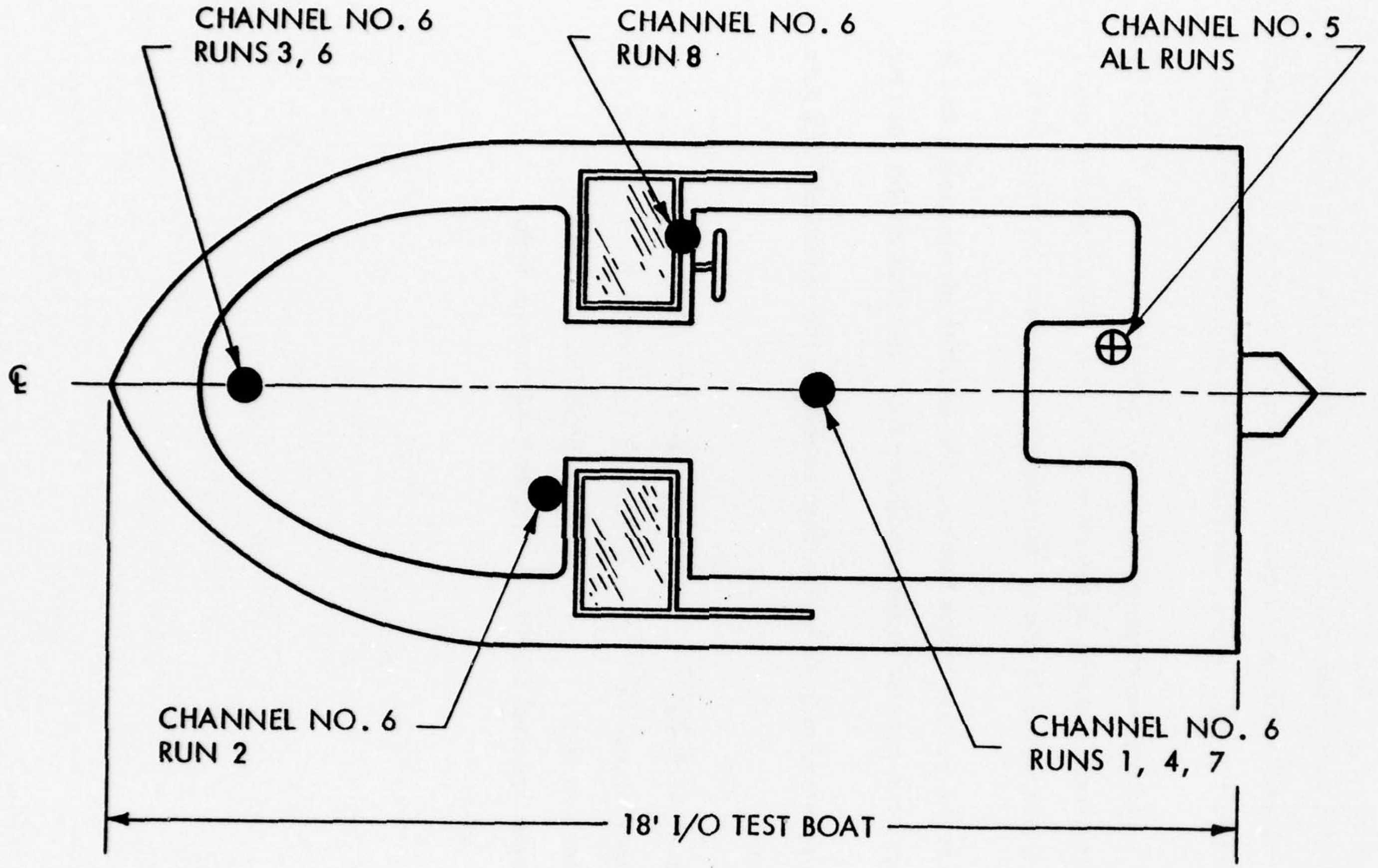


FIGURE B-1. LOCATIONS OF CHANNELS NO. 5 AND NO. 6 FOR WAVE DATA RETRIEVAL

Test Run Number	Location of Channel No. 5	Location of Channel No. 6	RPM and Speed	Water Condition
1	Aft position	Midship centerline	4100 rpm at 44 mph	2-3 in. chop
2	Aft position	Port gunwale 1/3 aft from bow tip	4100 rpm at 44 mph	3-4 in. chop
3	Aft position	Bow centerline	4100 rpm at 44 mph	4-6 in. chop
4	Aft position	Midship centerline	4100 rpm at 44 mph	4-6 in. chop
6	Aft position	Bow centerline	2000 rpm * at 20 mph	4-6 in. chop
7	Aft position	Midship centerline	2000 rpm at 20 mph	4-6 in. chop
8	Aft position	Control console next to steering location	4100 rpm at 44 mph	4-6 in. chop

* 2000 rpm is minimum planing speed

TABLE B-1. CHANNEL LOCATIONS, BOAT SPEED, AND WATER CONDITIONS PER TEST RUN

90%

292-531

193

195

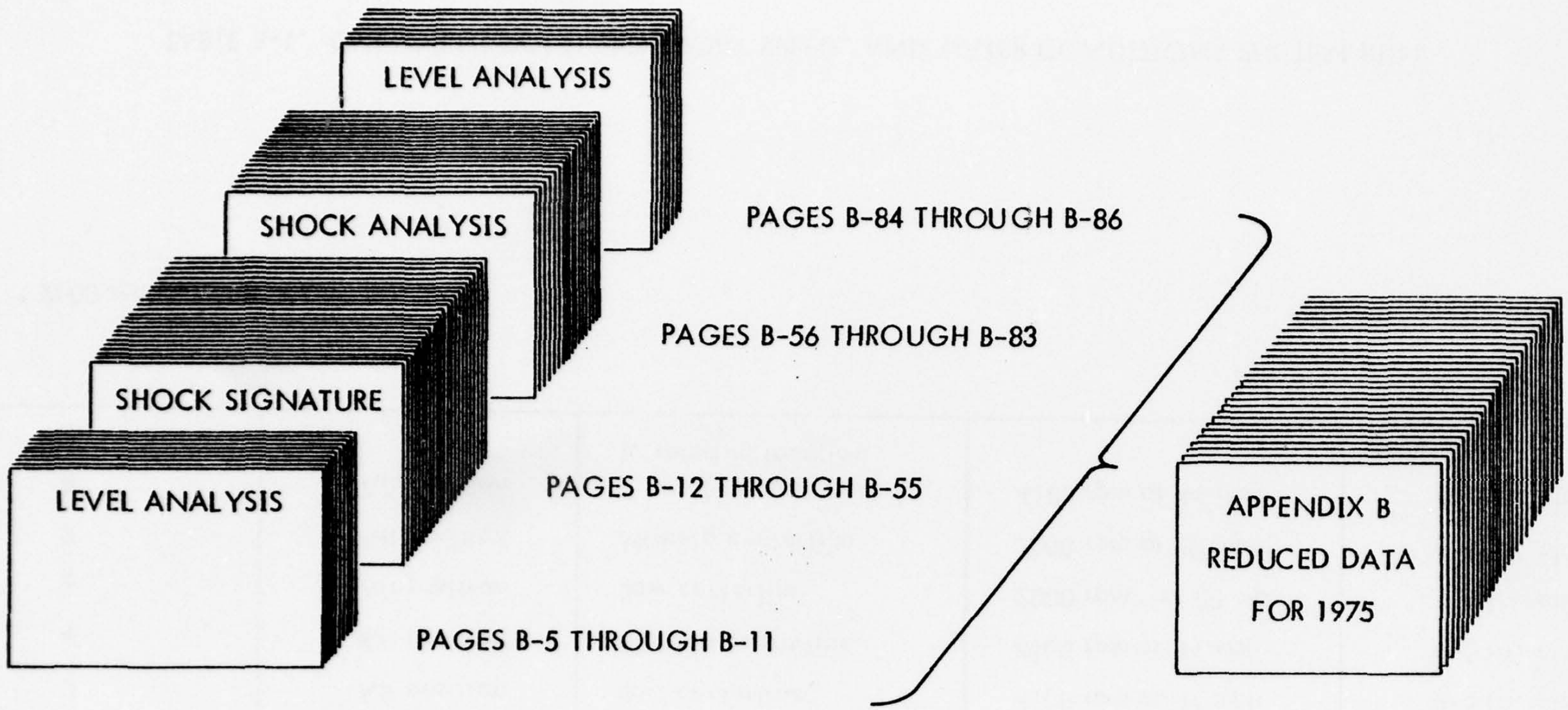
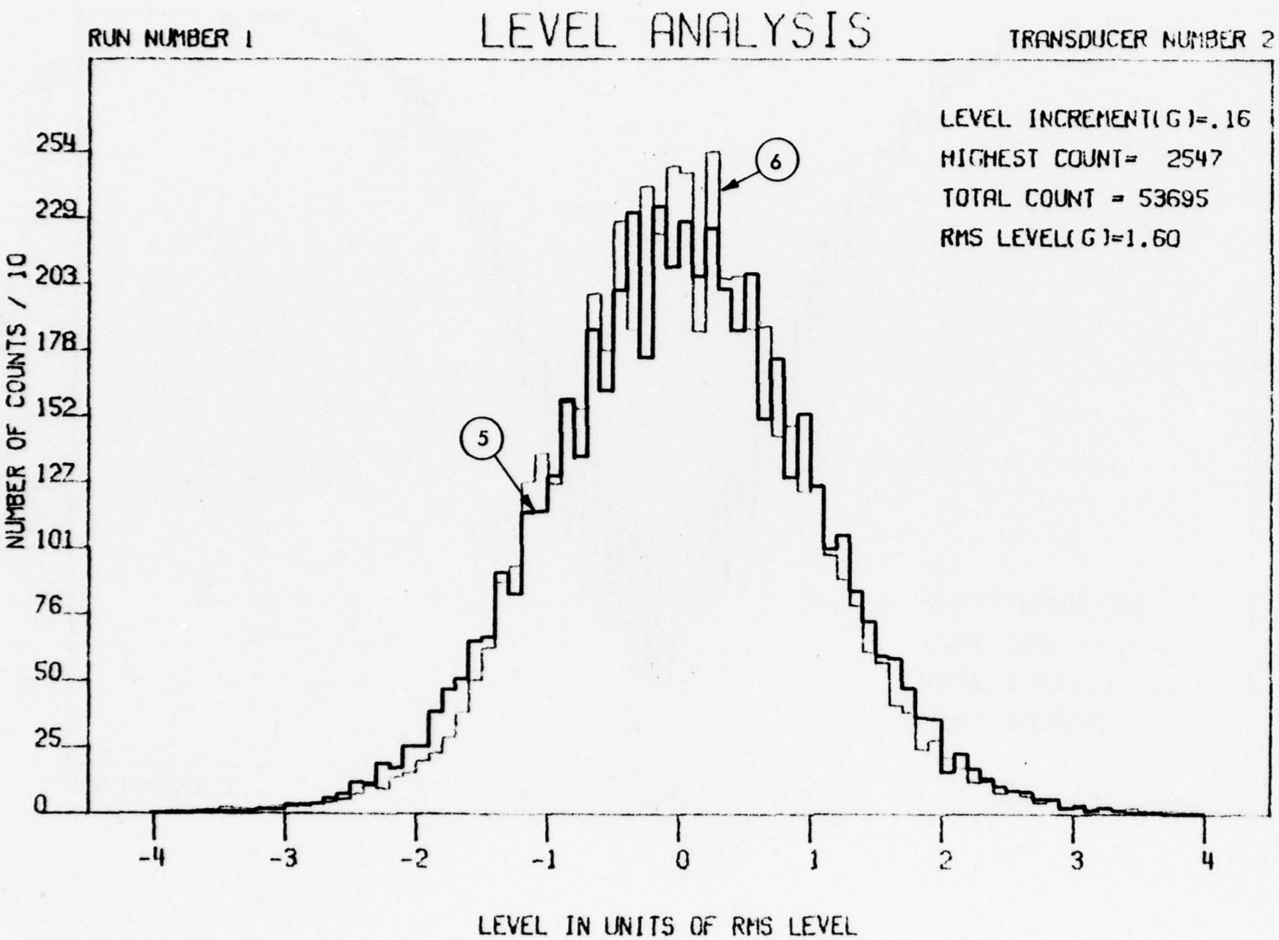


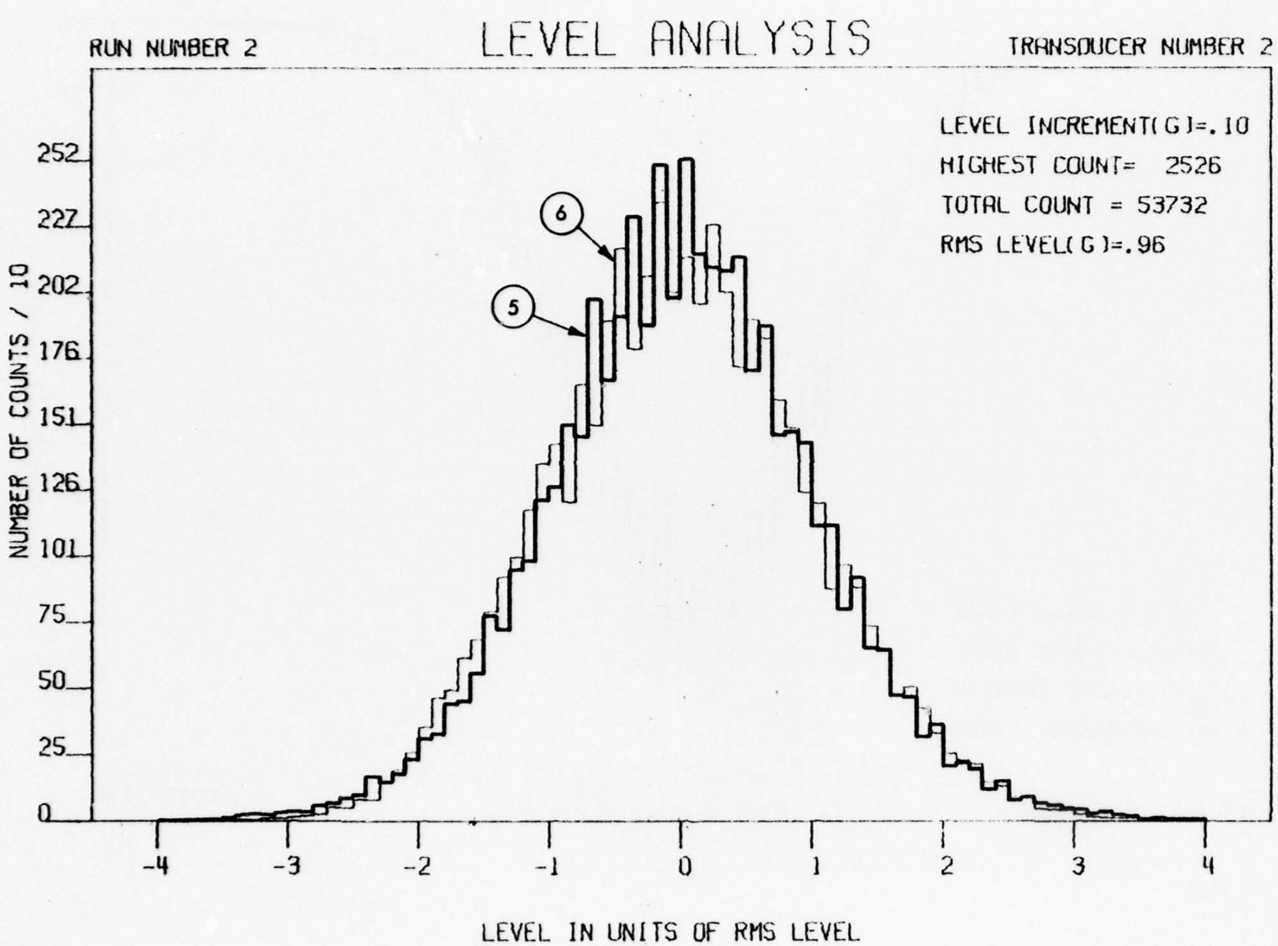
FIGURE B-2. APPENDIX B COMPILATION



292-531

195

197



292-531

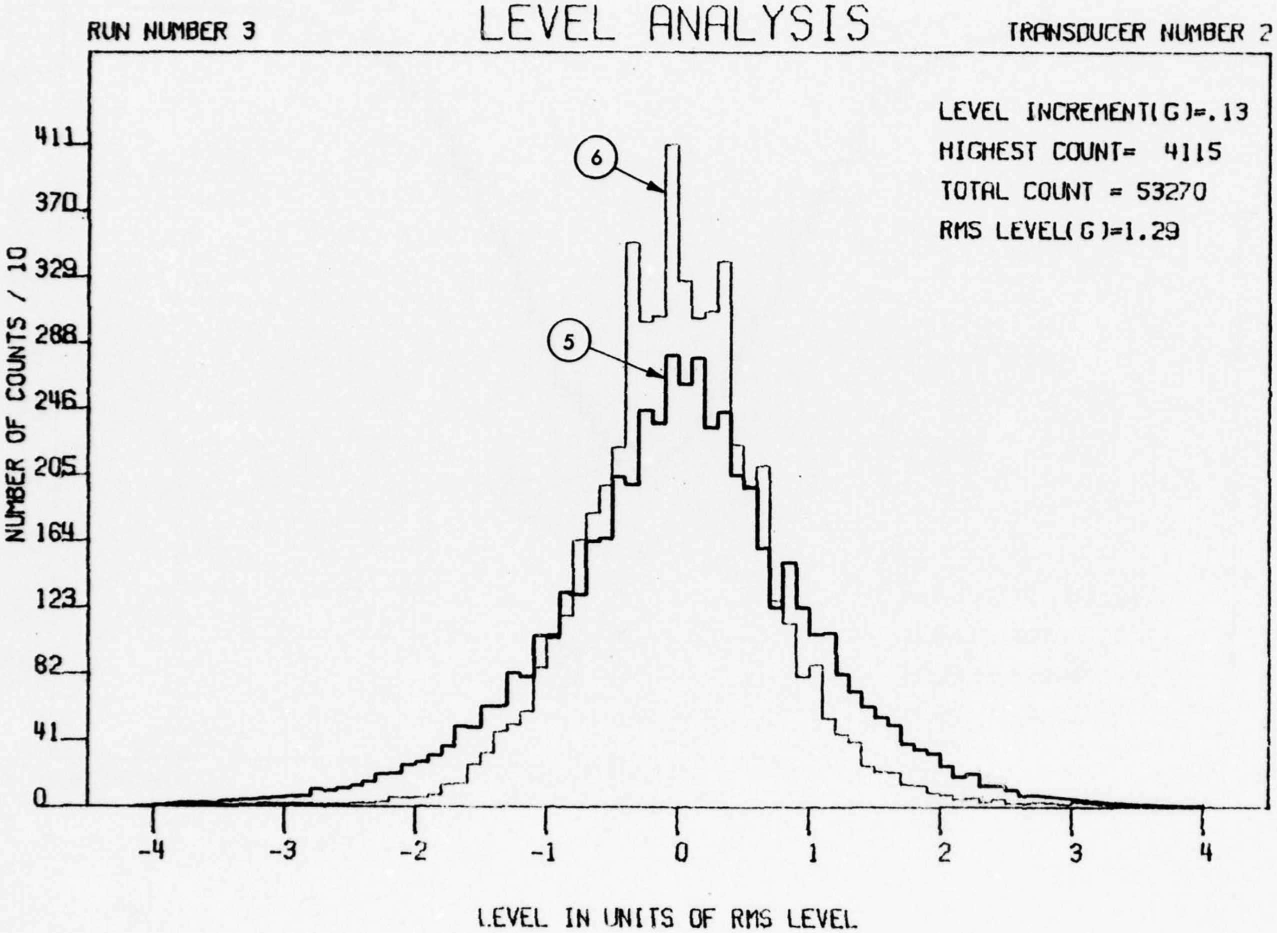
196

198

202

3 12:27

LEVEL ANALYSIS



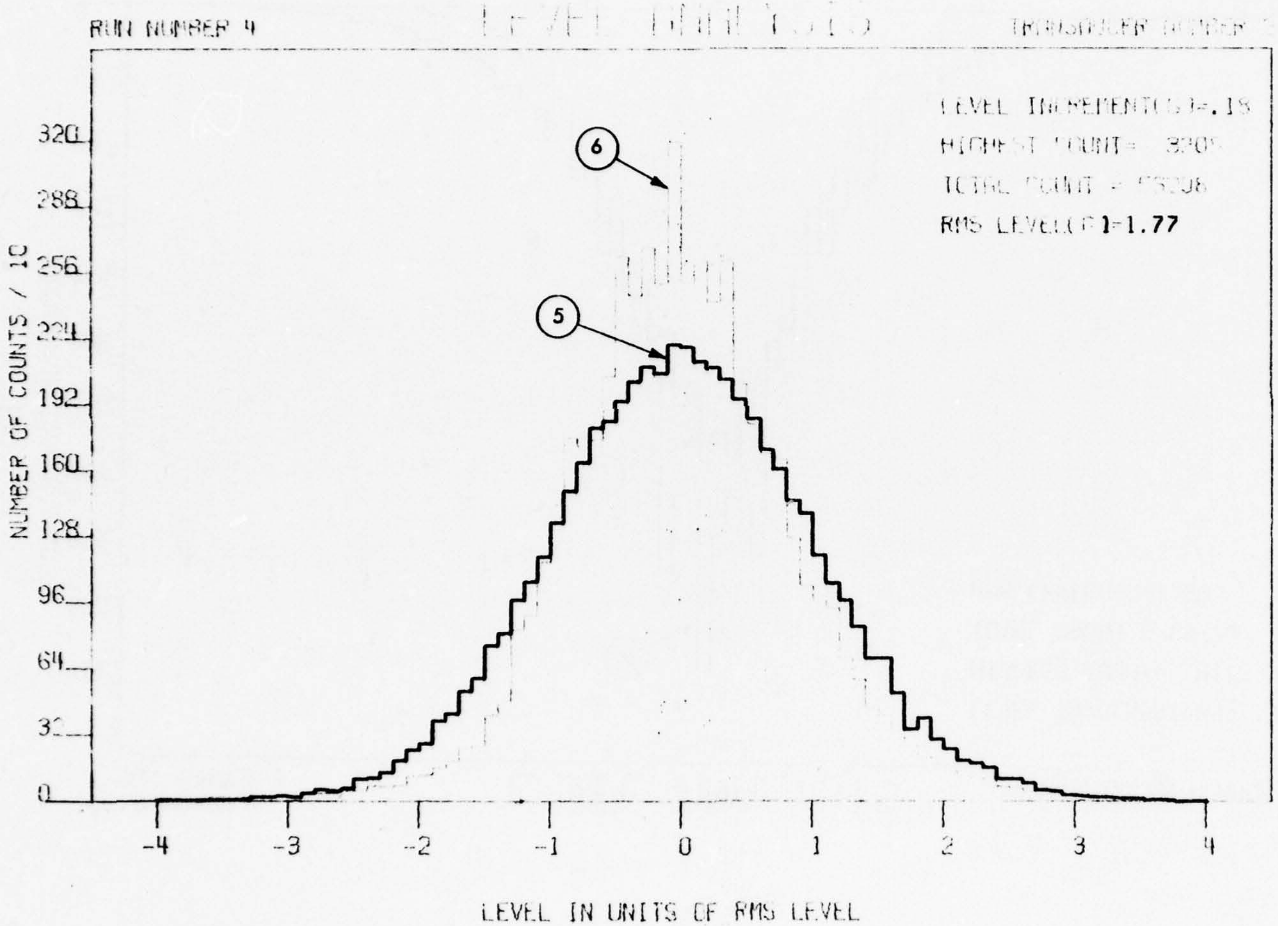
292-531

197

199

4

12.29

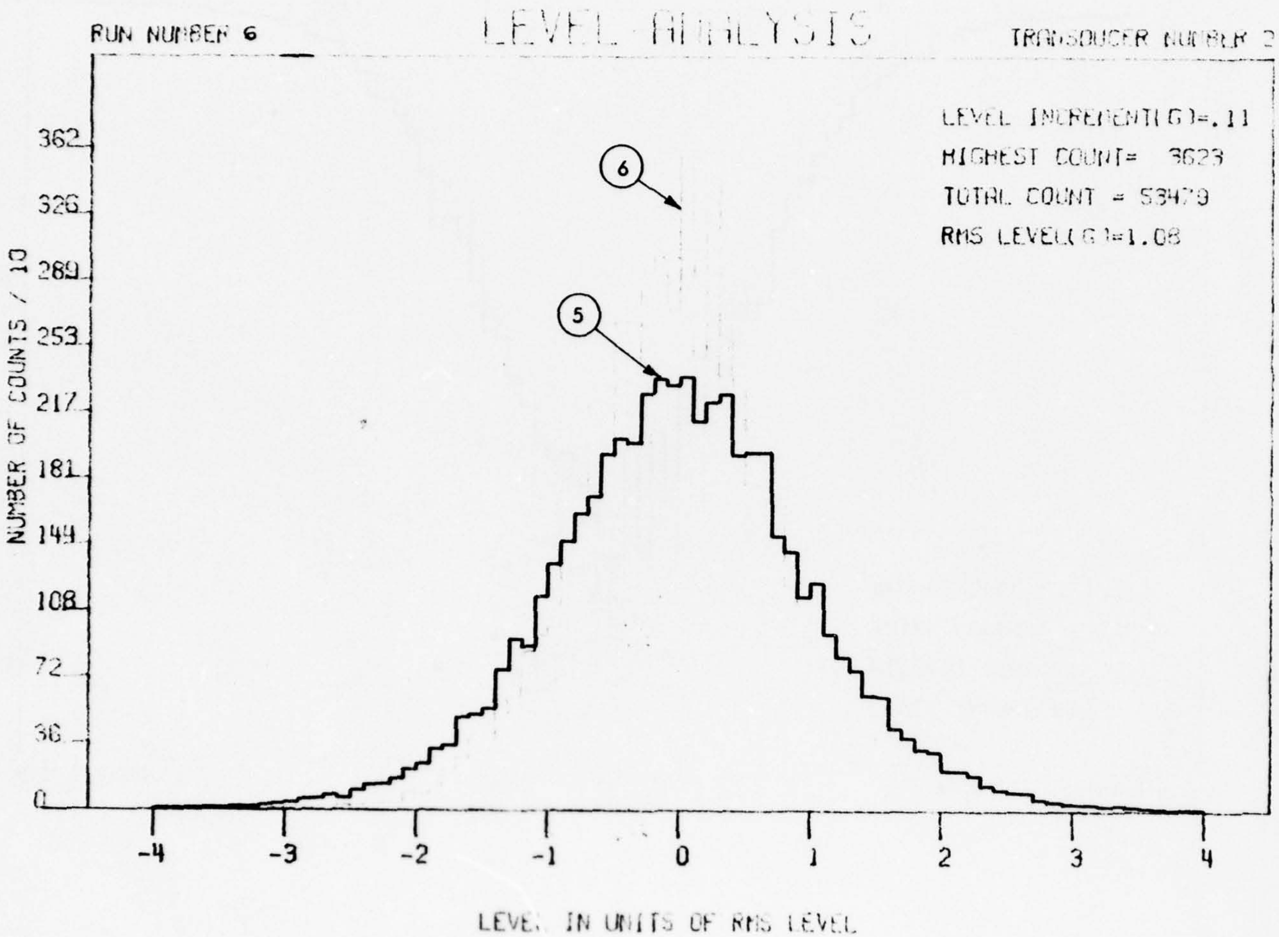


19

292-531

198

200

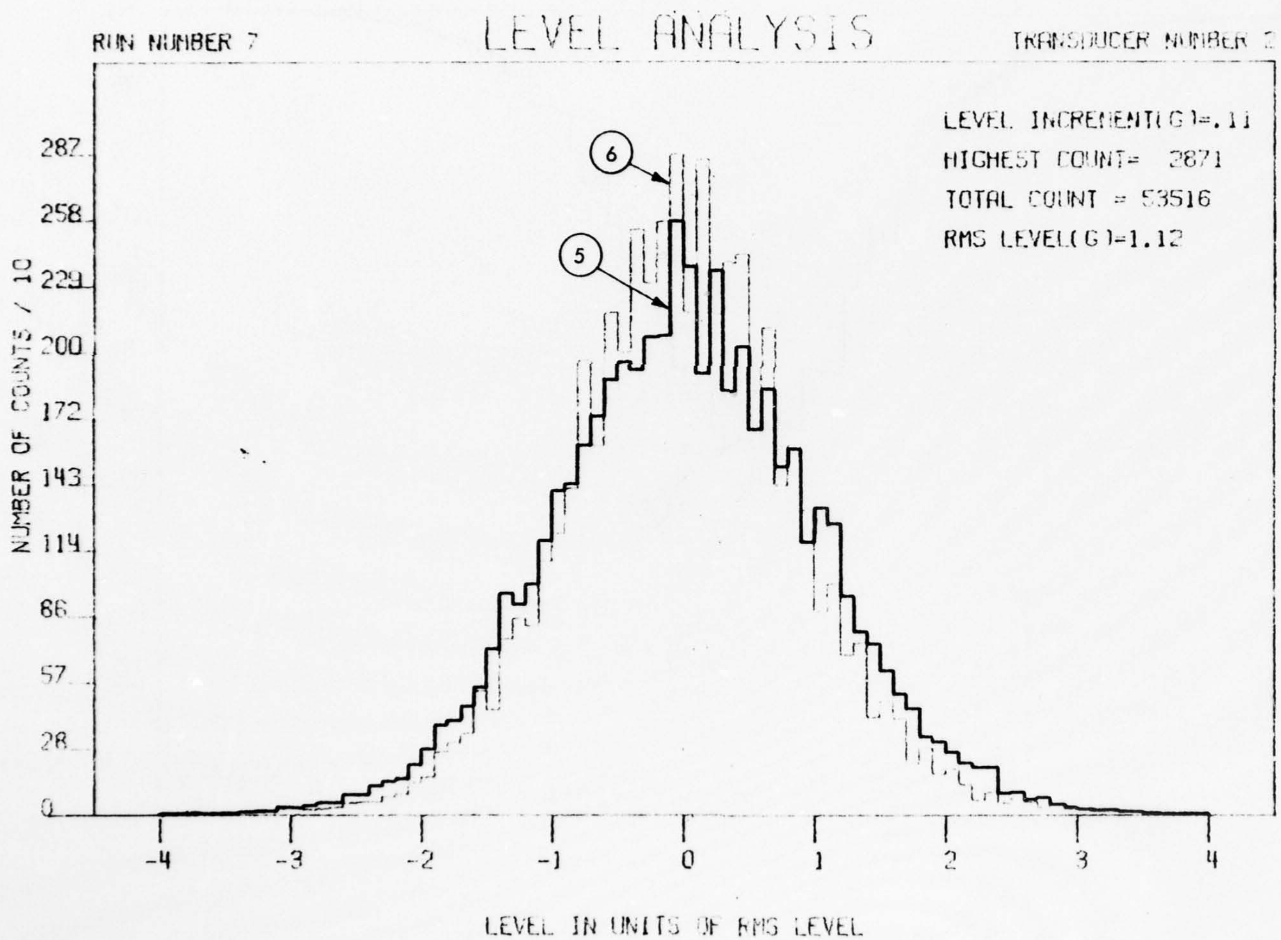


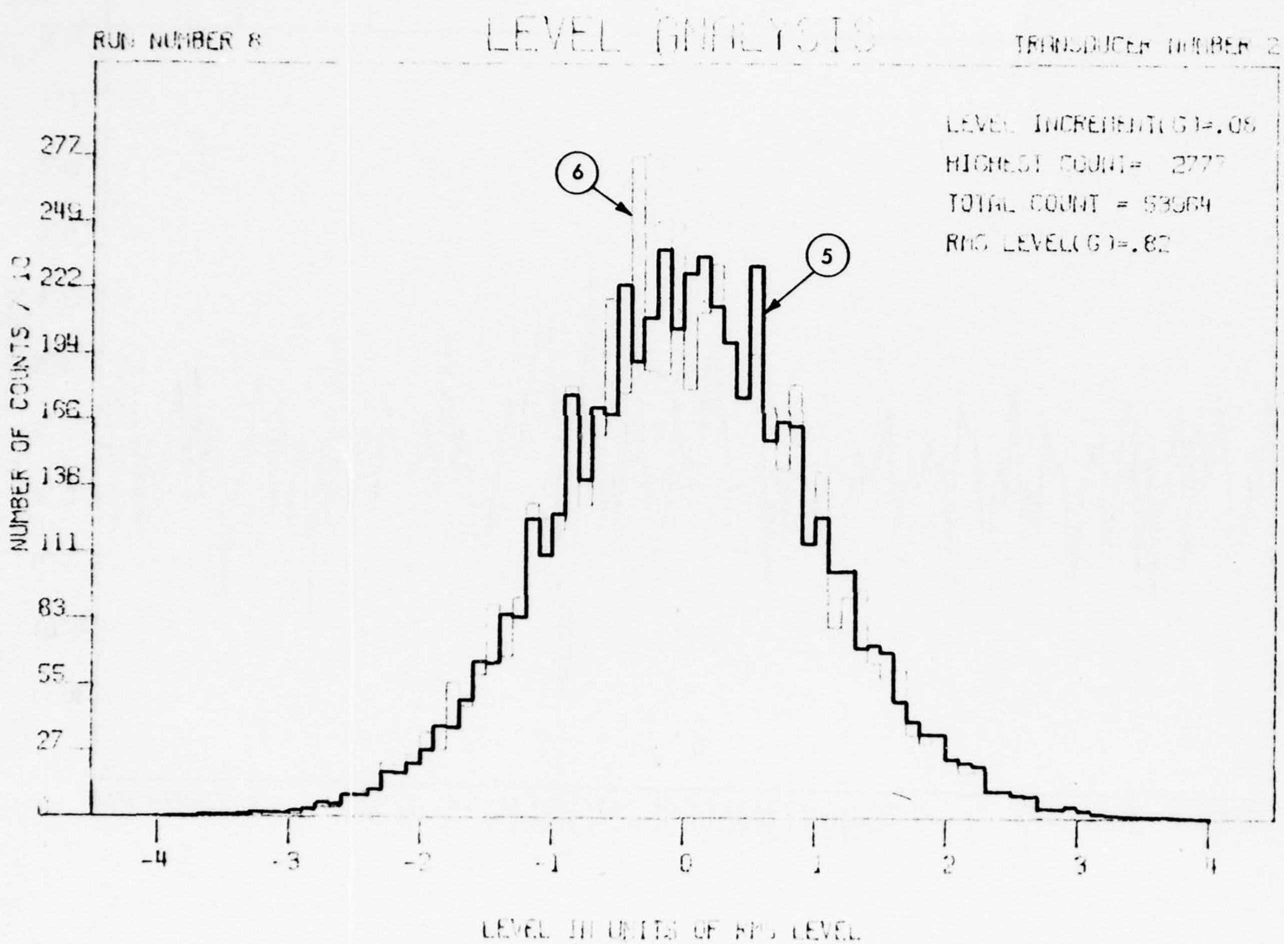
B-9

292-531 (199)

(201) (205)

27

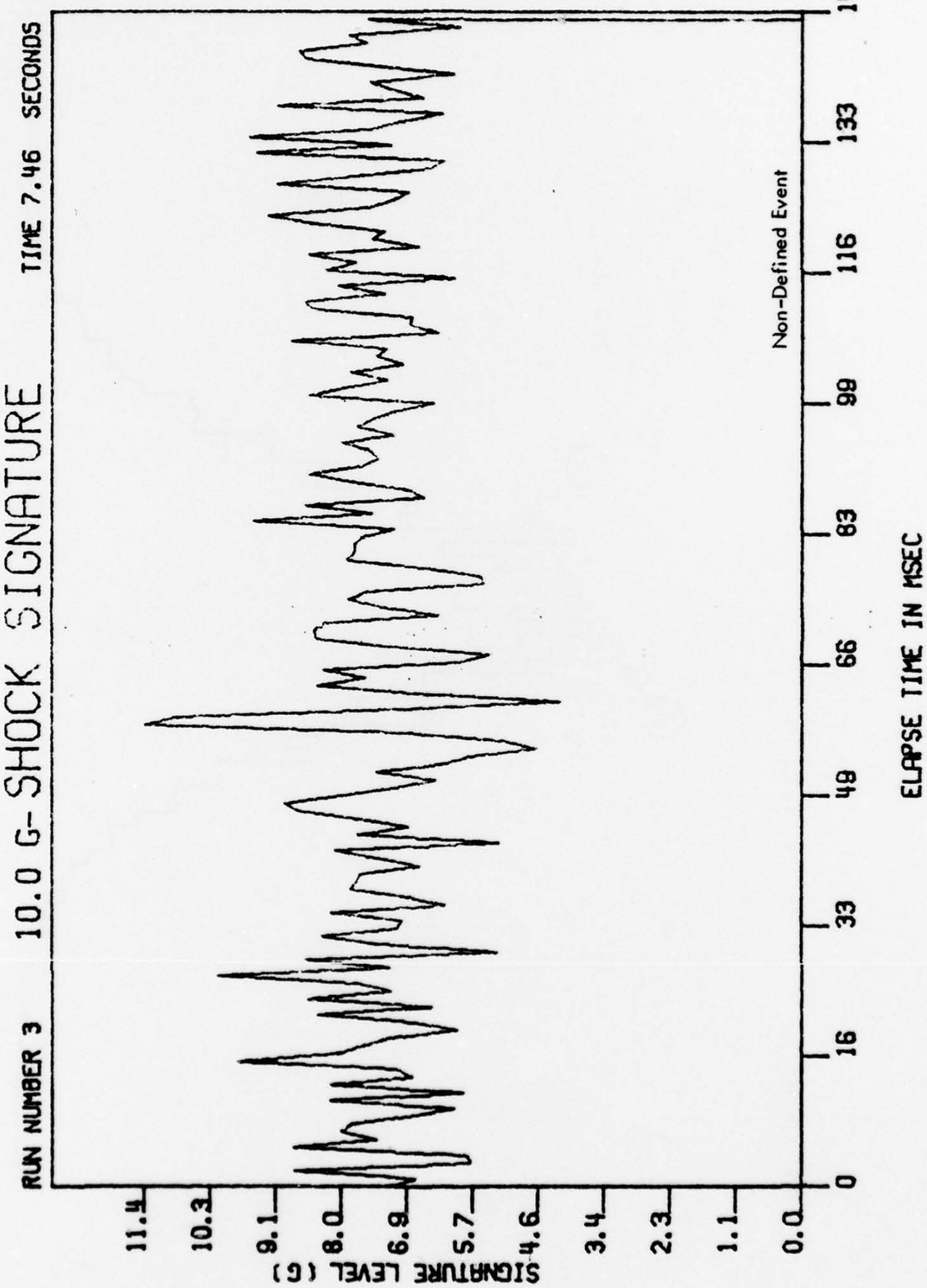

RUN NUMBER 7
LEVEL ANALYSIS
TRANSDUCER NUMBER 2
LEVEL INCREMENT(G)=.11
HIGHEST COUNT= 2871
TOTAL COUNT = 53516
RMS LEVEL(G)=1.12
6
5
NUMBER OF COUNTS / 10
287
258
229
200
172
143
114
86
57
28
0
-4
-3
-2
-1
0
1
2
3
4
LEVEL IN UNITS OF RMS LEVEL



B-11

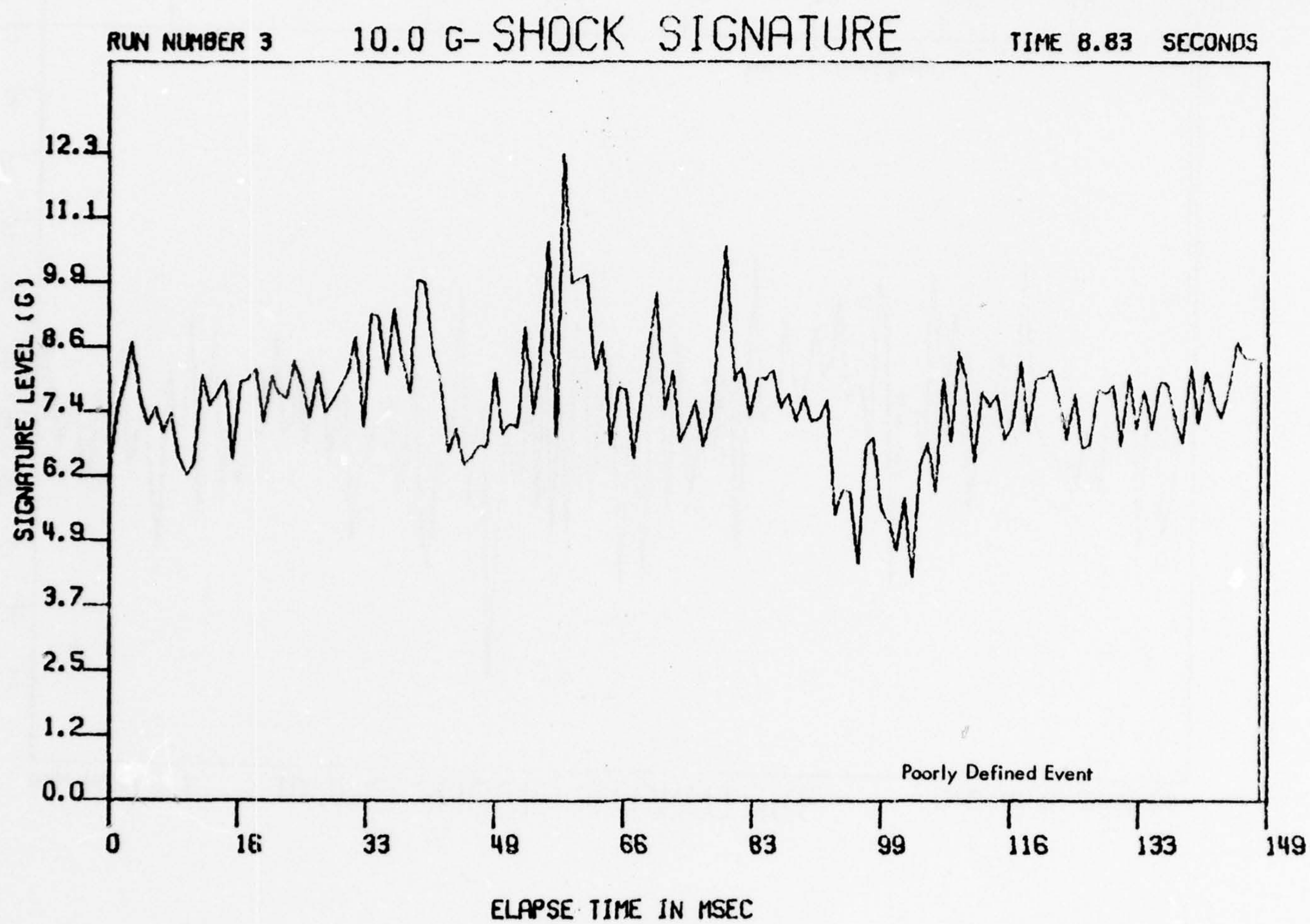
292-531 201

203



292-531 (202)

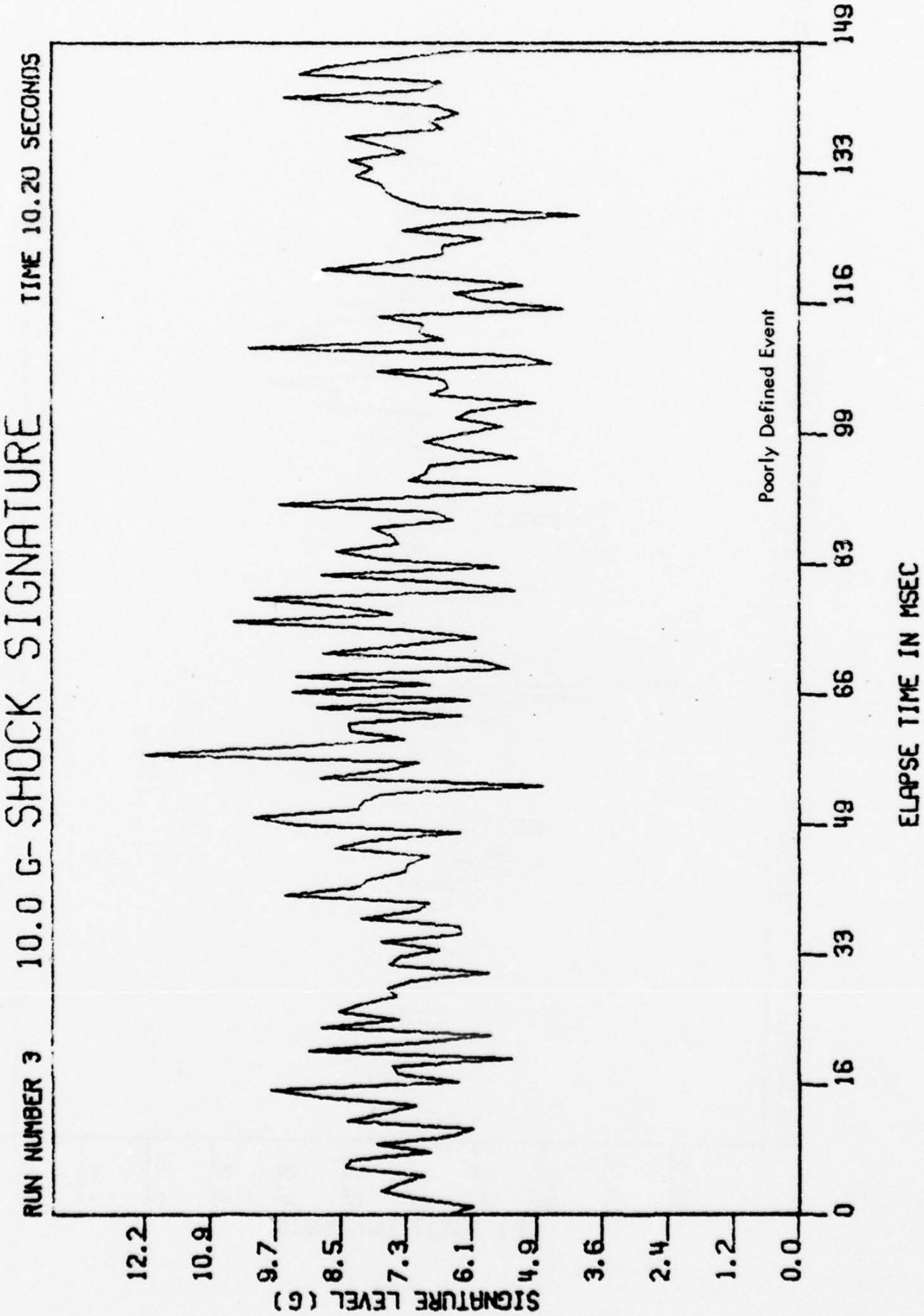
(204)



292-531

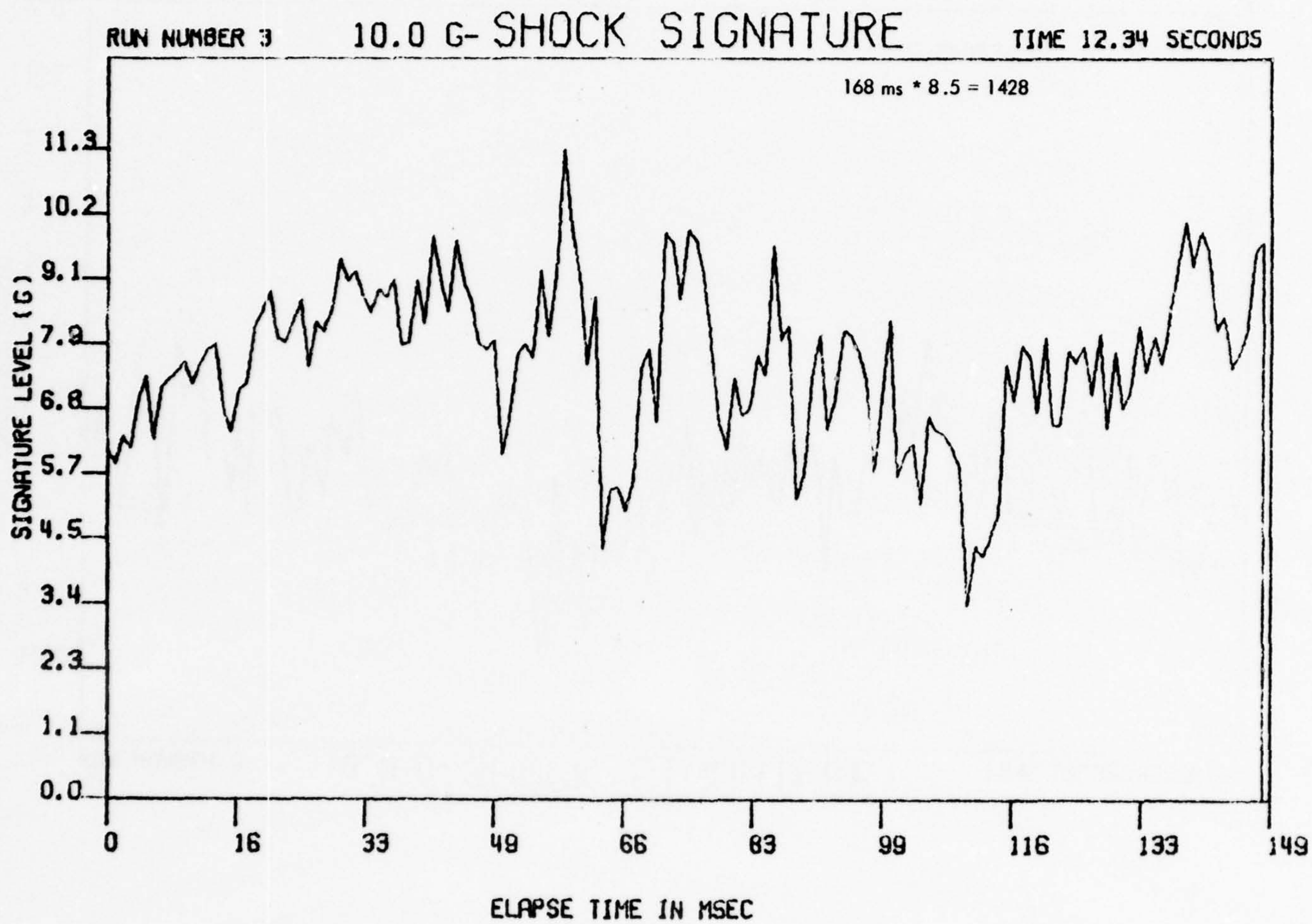
203

205


RUN NUMBER 3
10.0 G- SHOCK SIGNATURE
TIME 10.20 SECONDS
Poorly Defined Event
SIGNATURE LEVEL (G)
12.2
10.9
9.7
8.5
7.3
6.1
4.9
3.6
2.4
1.2
0.0
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC

292-531

204

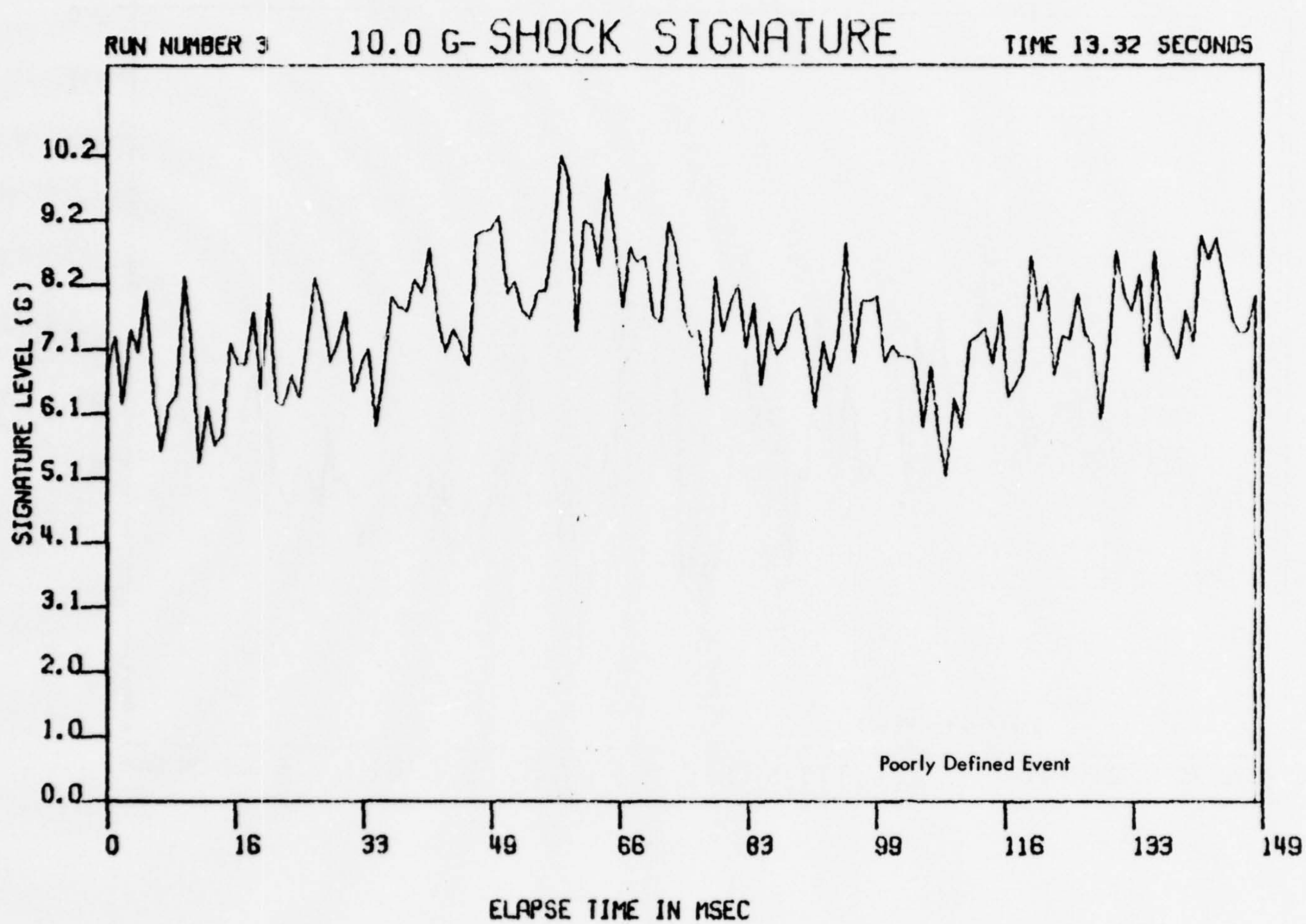


292-531

205

207

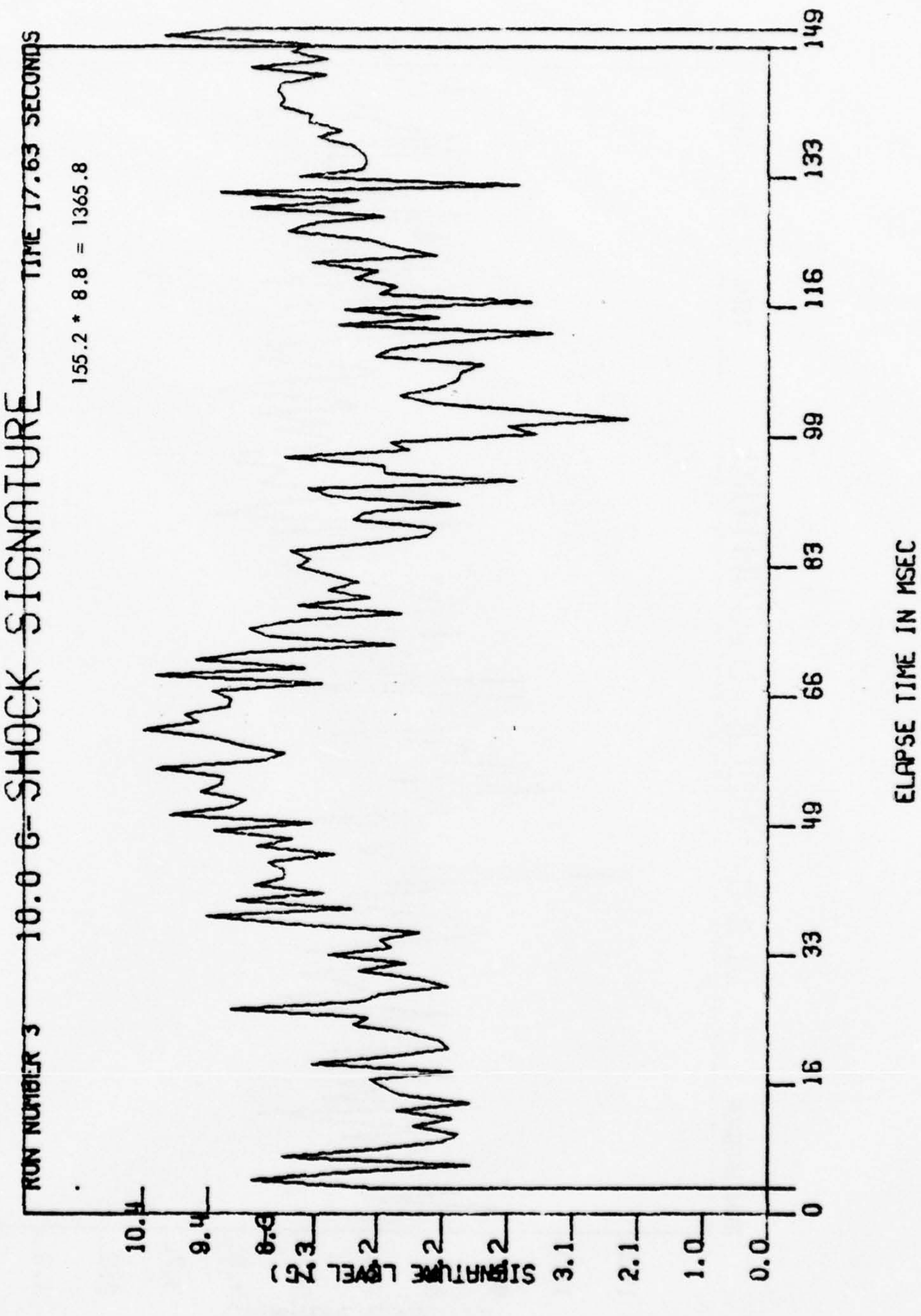
211



292-531

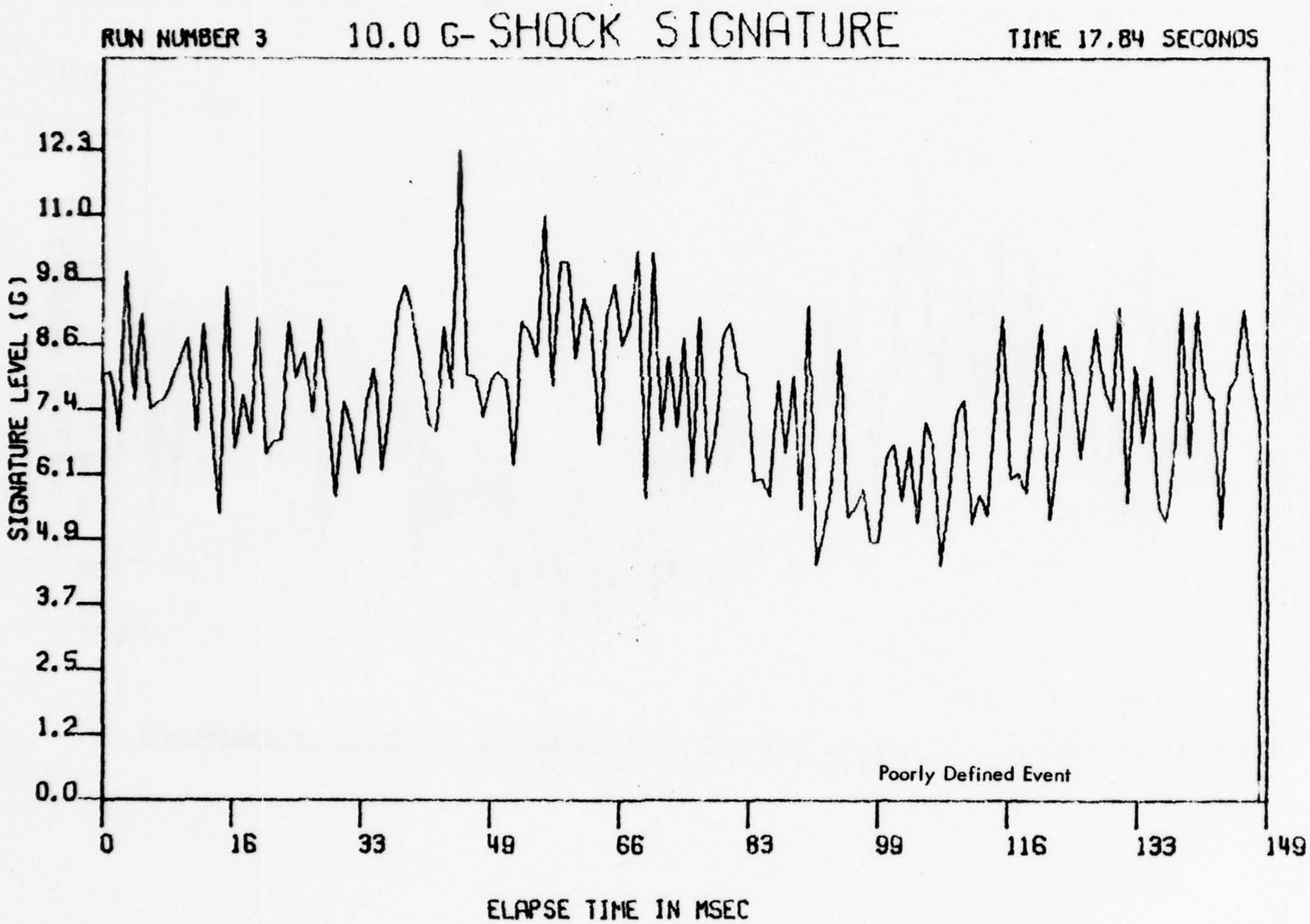
206

208



292-531 (207)

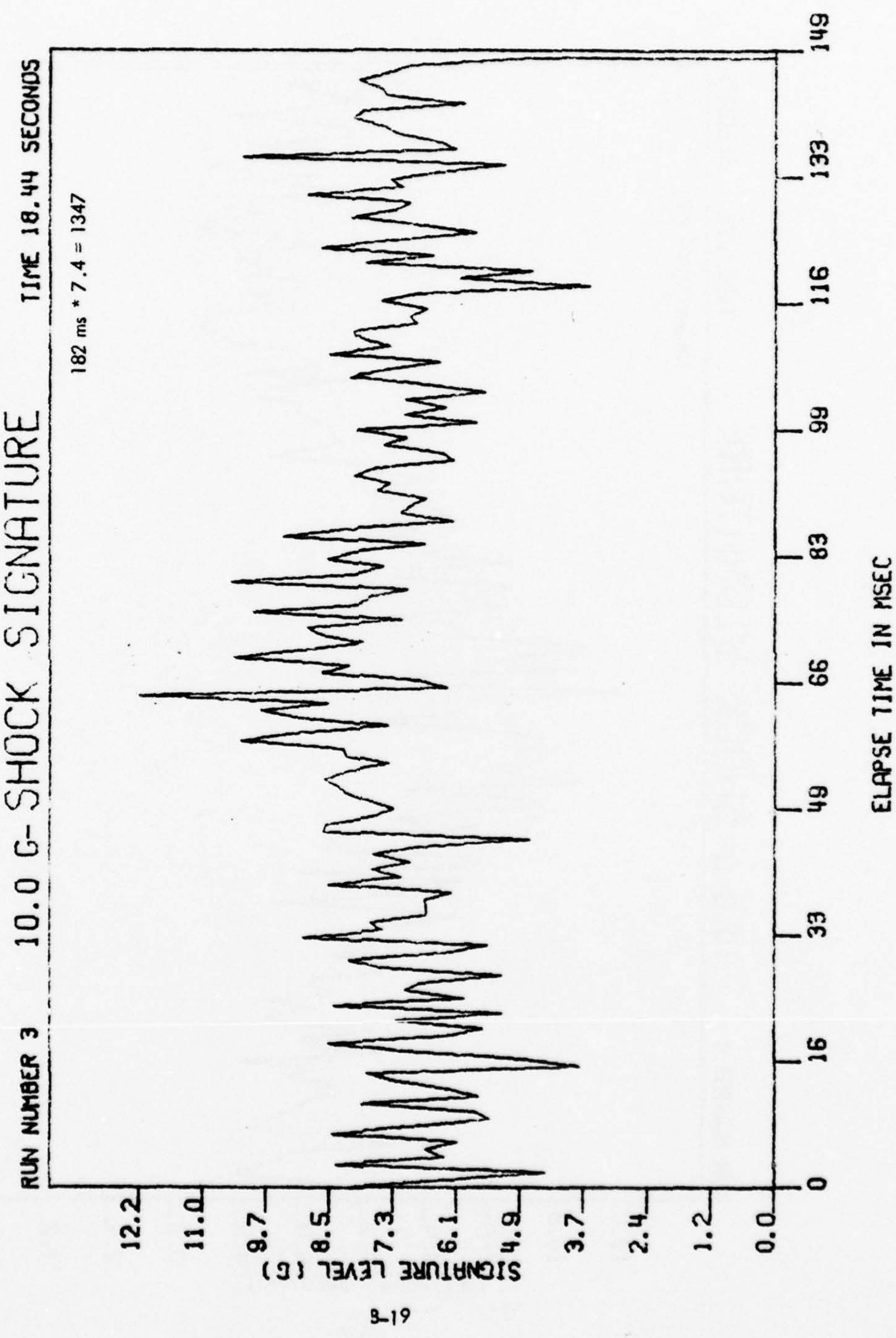
209 210

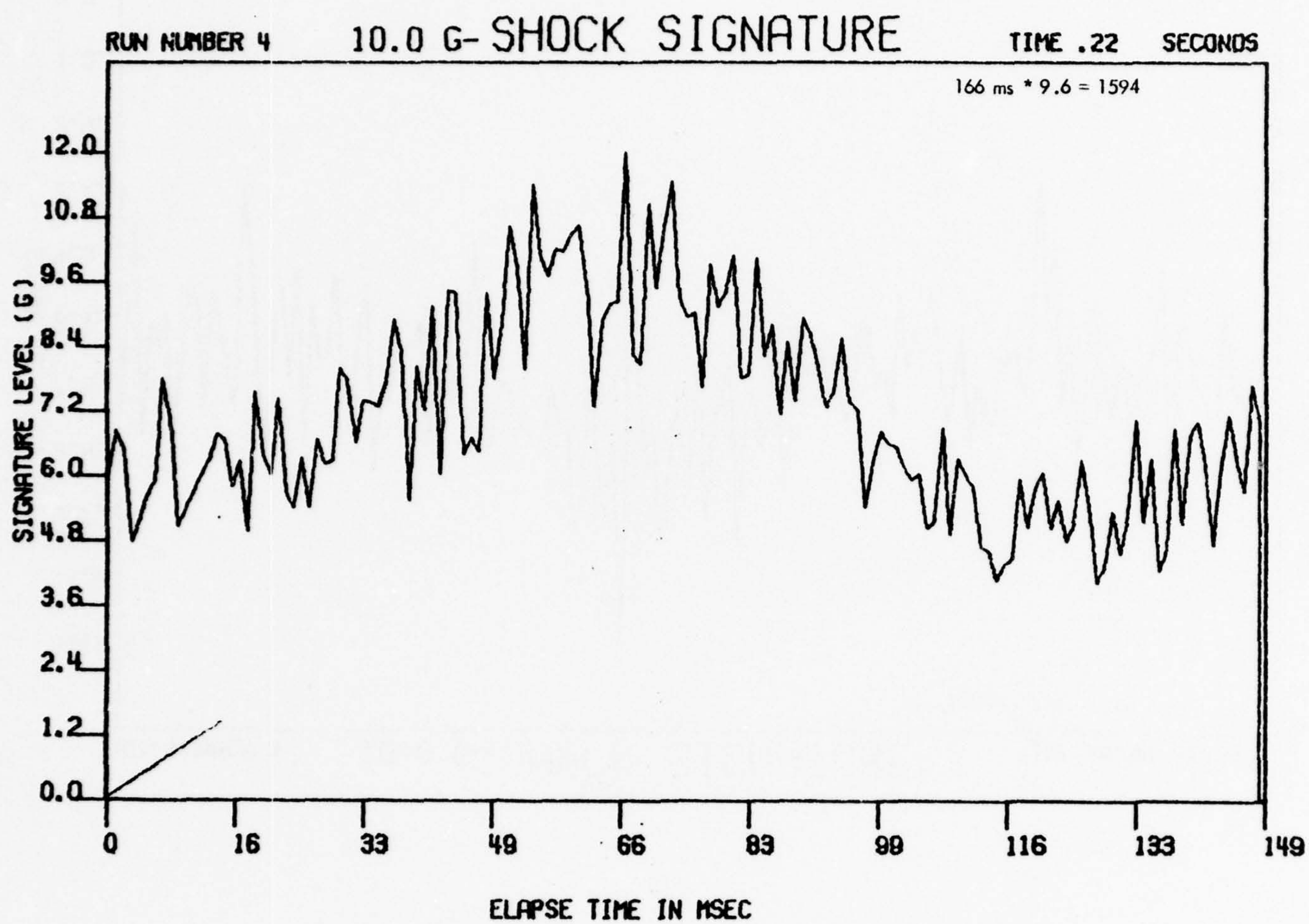


292-531

208

210

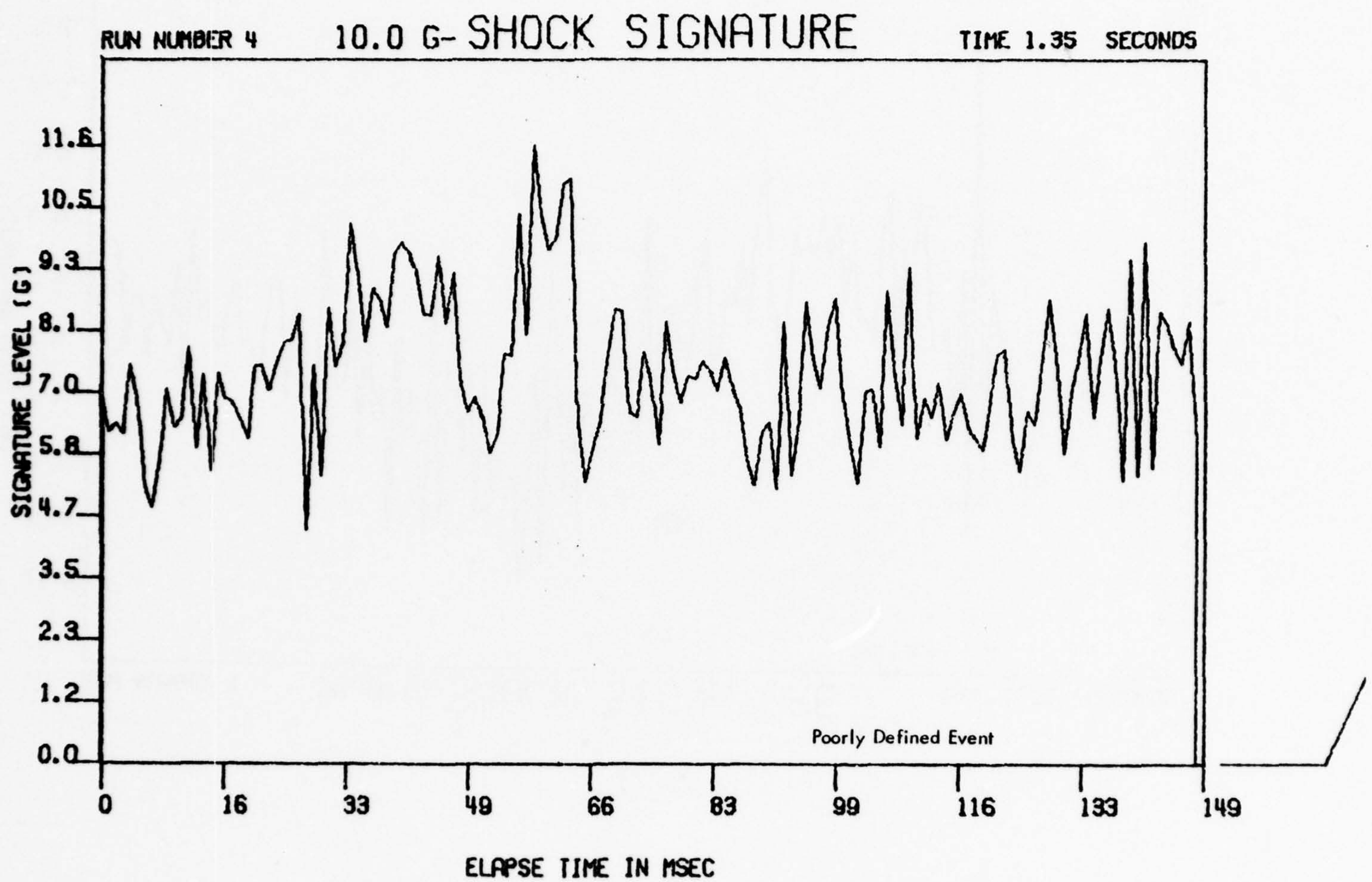

RUN NUMBER 3
10.0 G- SHOCK SIGNATURE
TIME 18.44 SECONDS
182 ms * 7.4 = 1347
SIGNATURE LEVEL (G)
12.2
11.0
9.7
8.5
7.3
6.1
4.9
3.7
2.4
1.2
0.0
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC



292-531

210

212

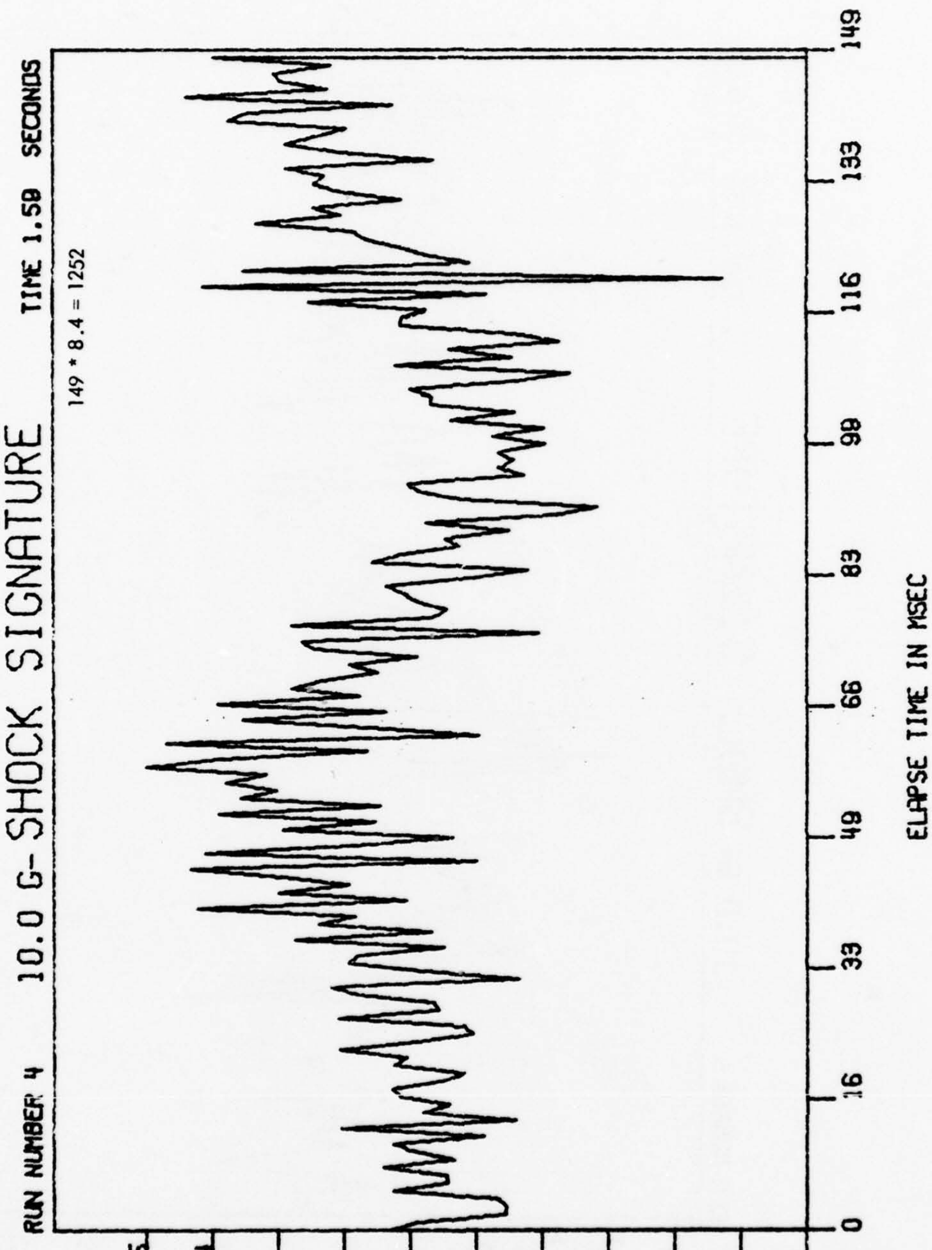


292-531

211

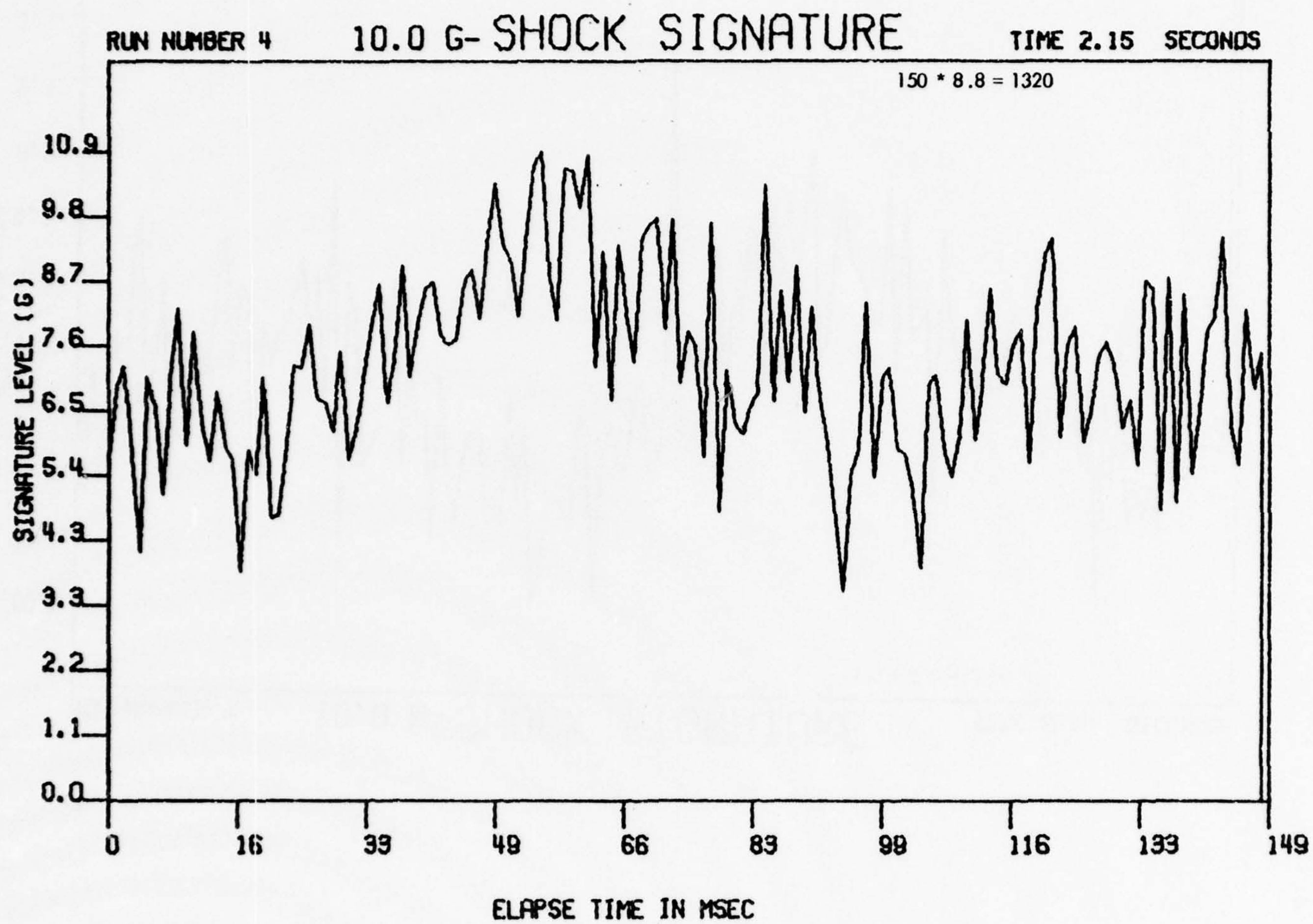
213

217



292-531 212

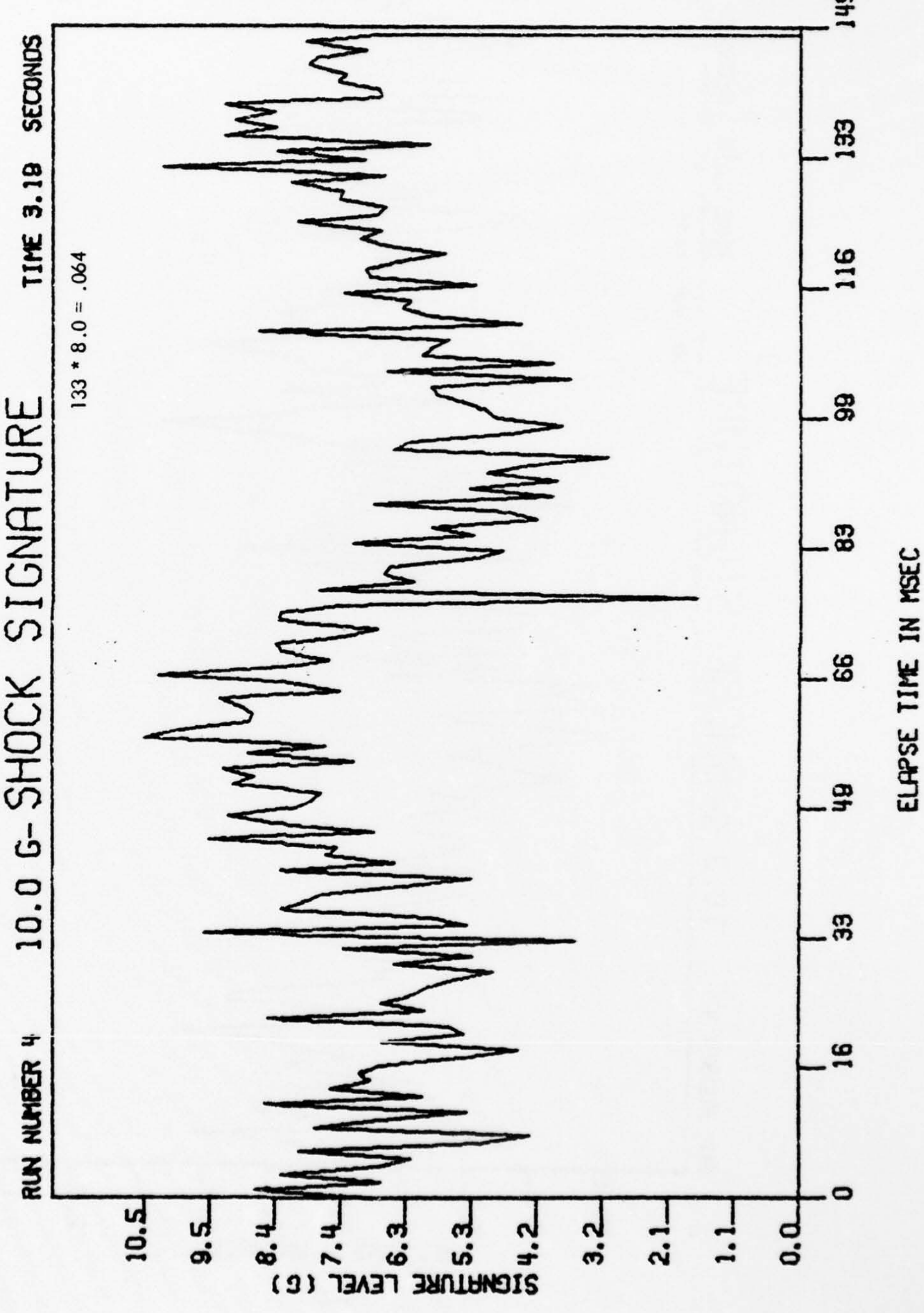
214 218



292-531

213

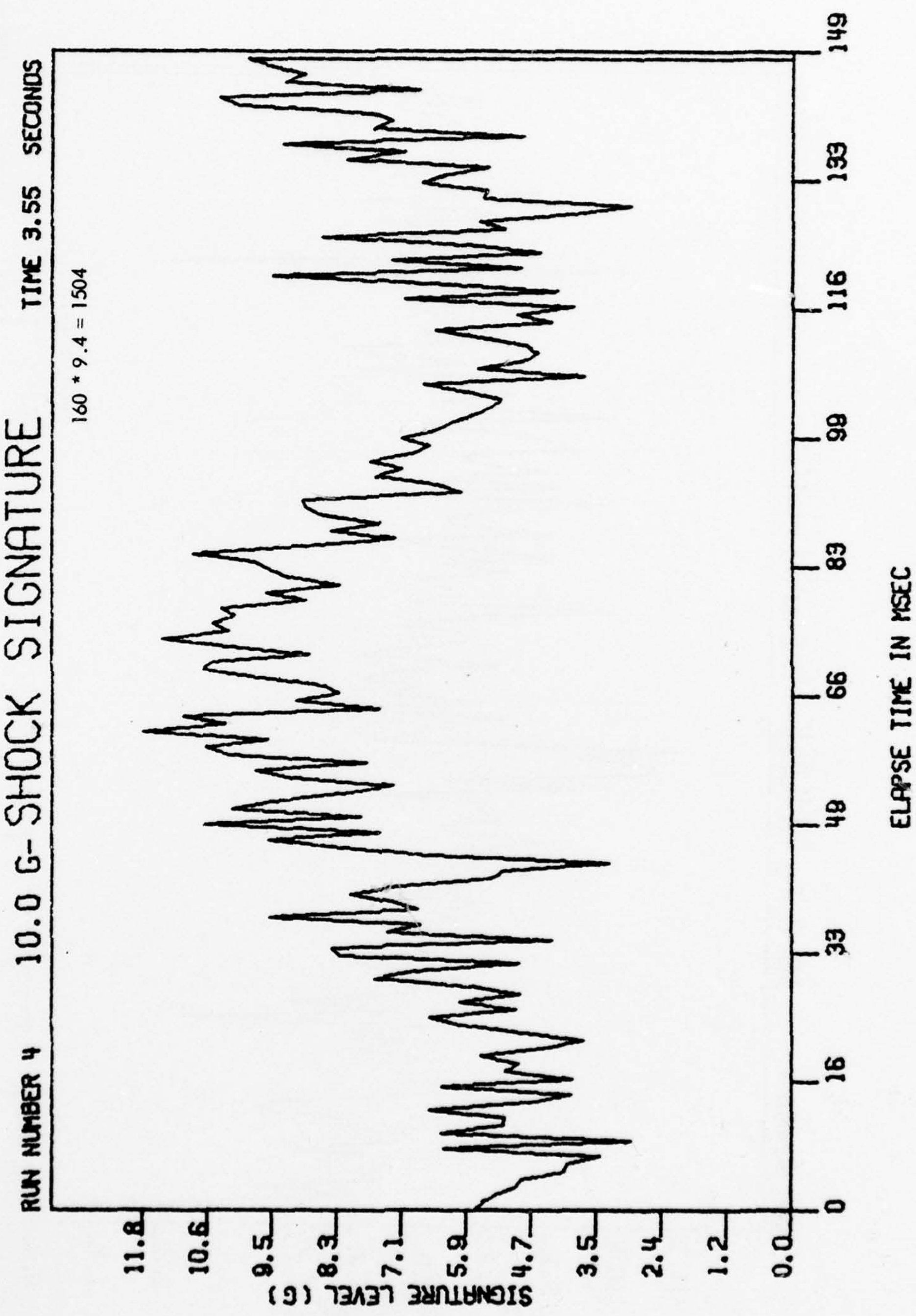
215

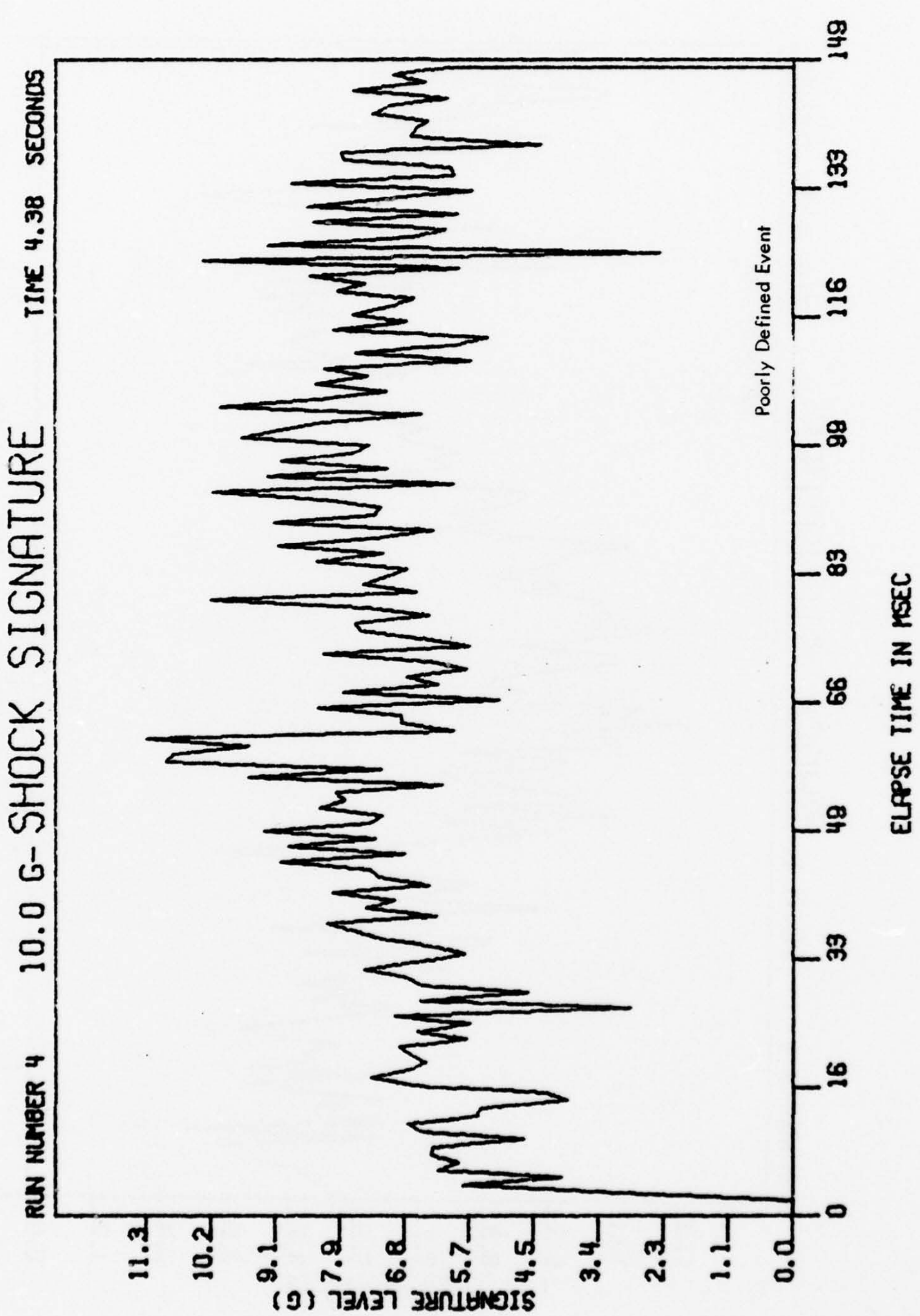


292-531

214

216

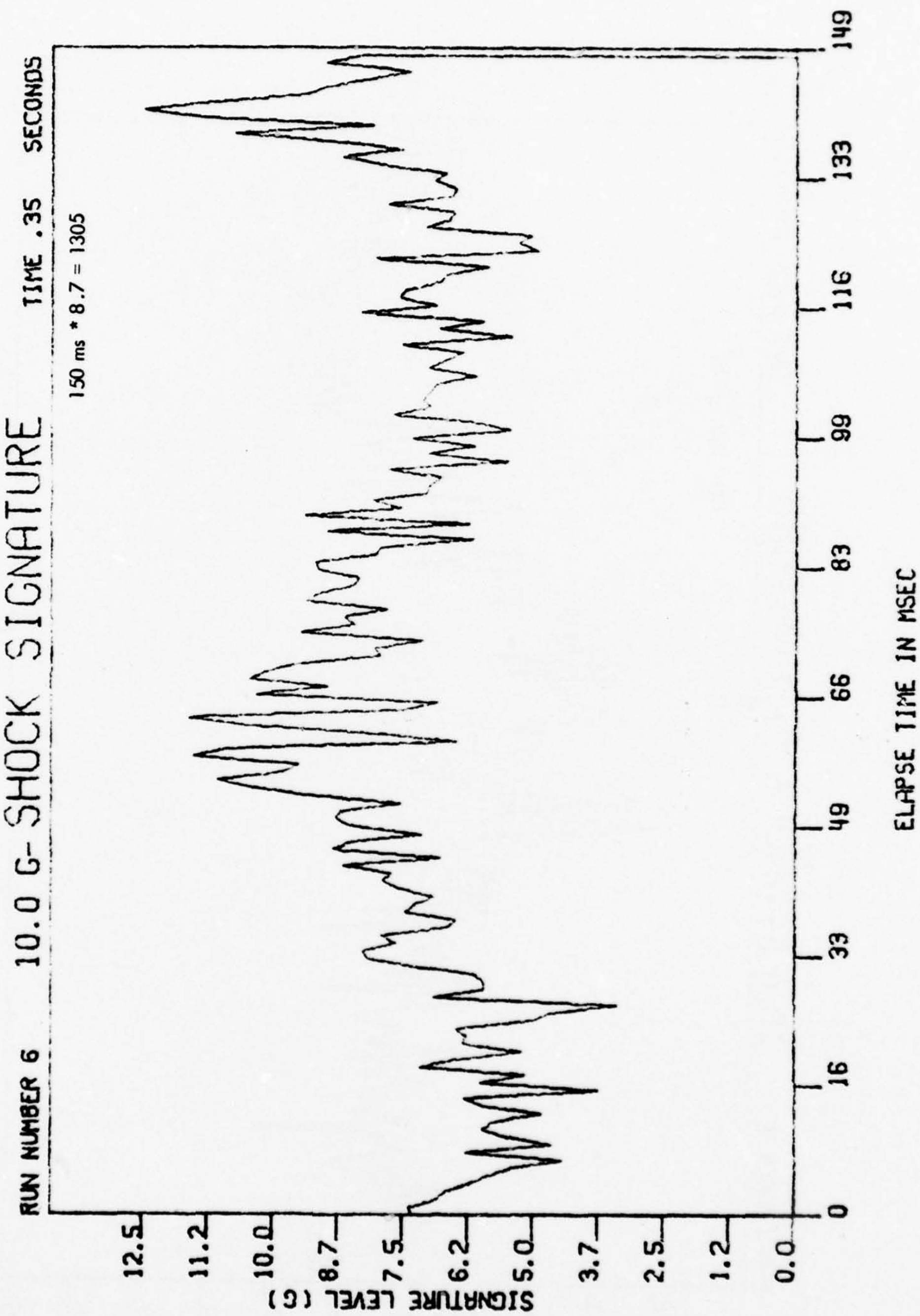

RUN NUMBER 4
10.0 G- SHOCK SIGNATURE
TIME 3.55 SECONDS
160 * 9.4 = 1504
SIGNATURE LEVEL (G)
11.8
10.6
9.5
8.3
7.1
5.9
4.7
3.5
2.4
1.2
0.0
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC



292-531

216

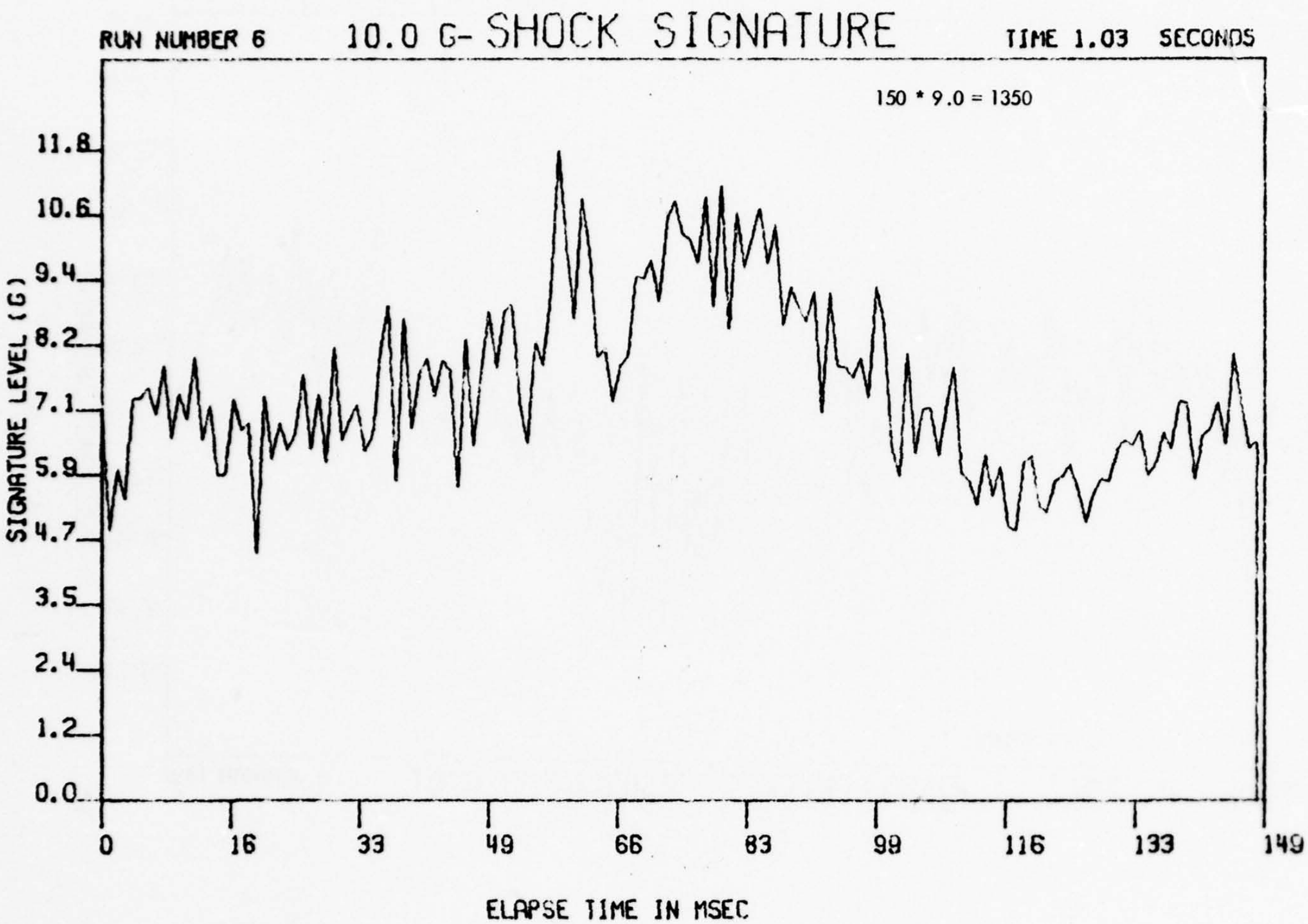
212



292-531

217

219

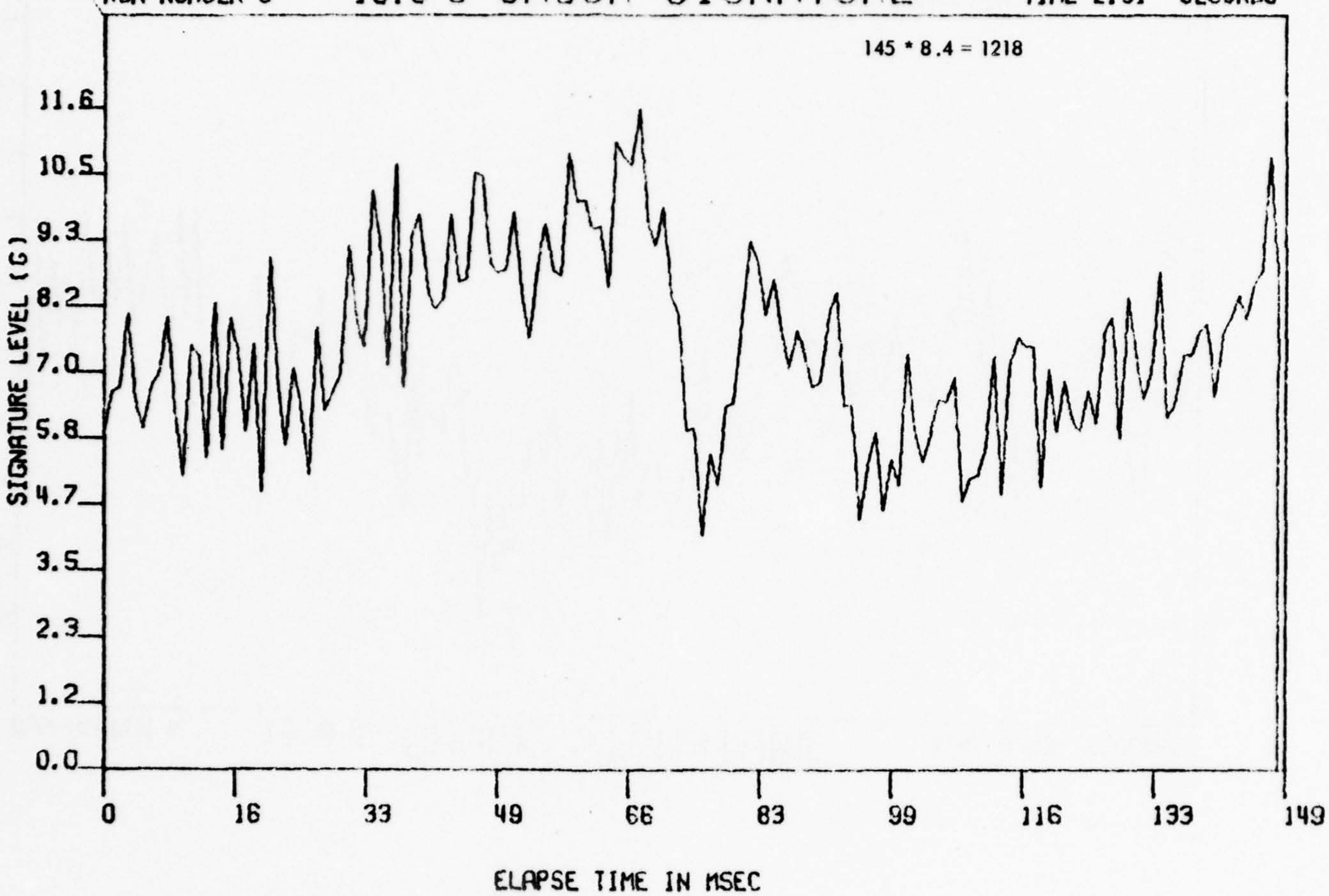


292-531 218

220

224

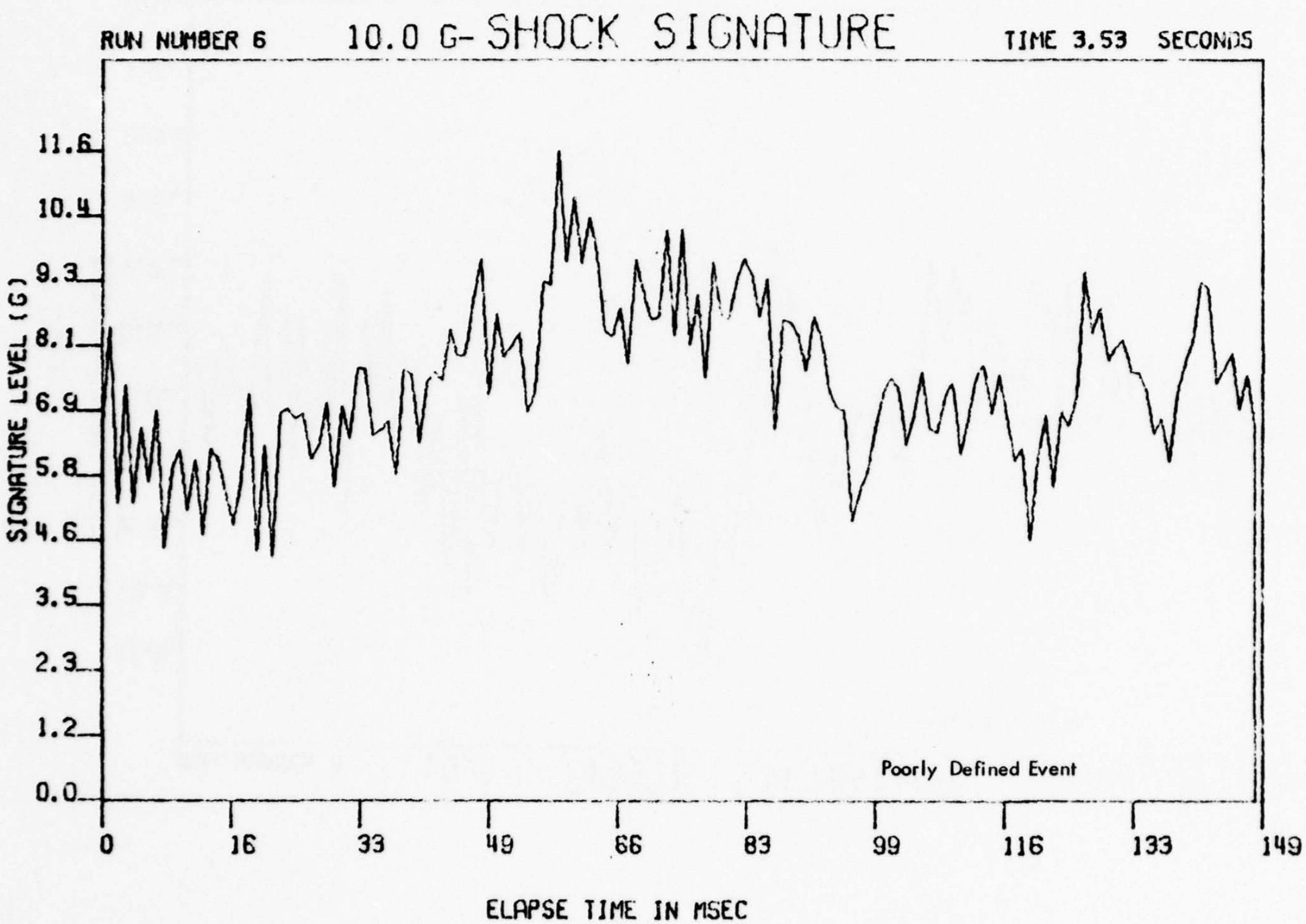
RUN NUMBER 6 10.0 G- SHOCK SIGNATURE TIME 2.31 SECONDS



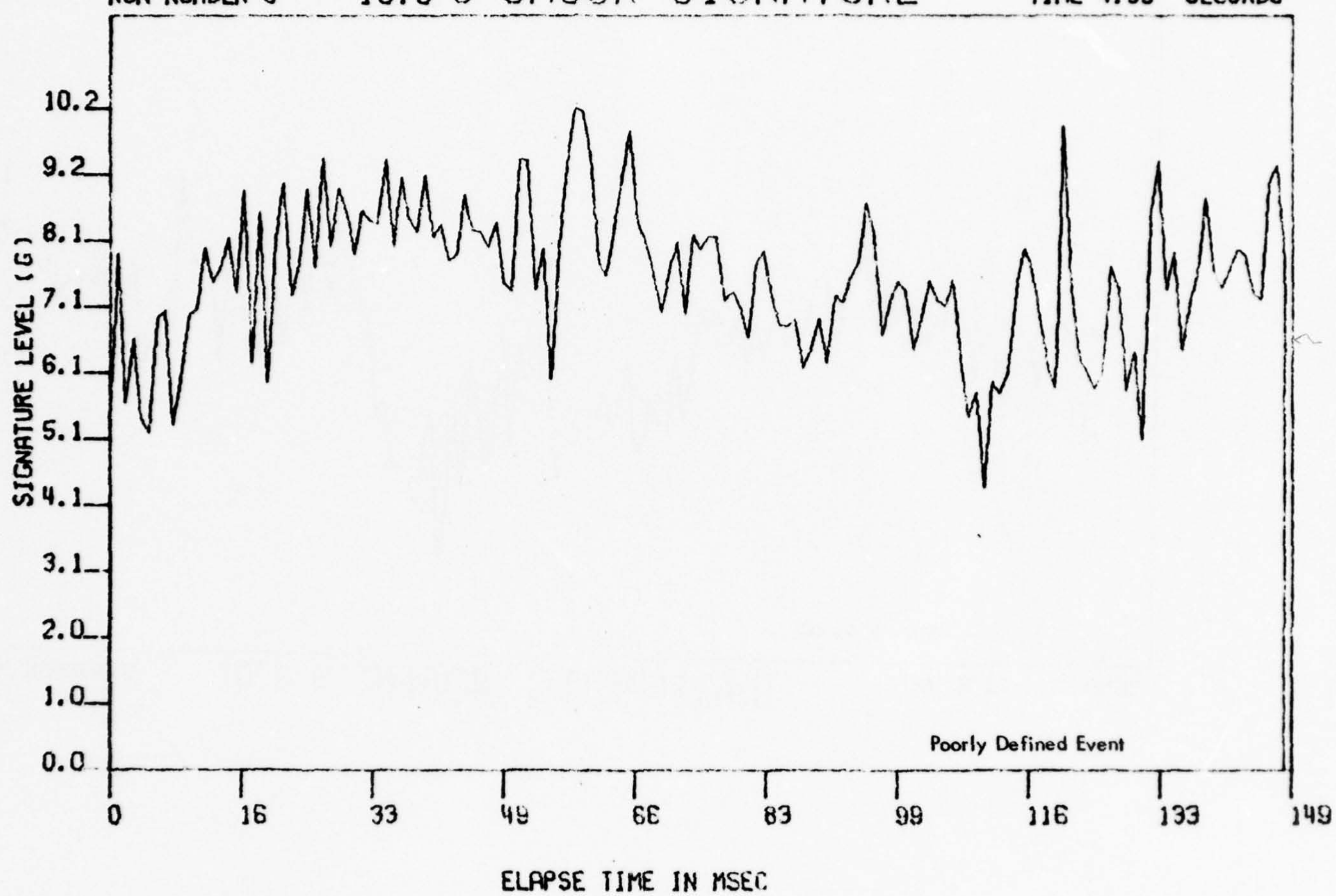
292-531

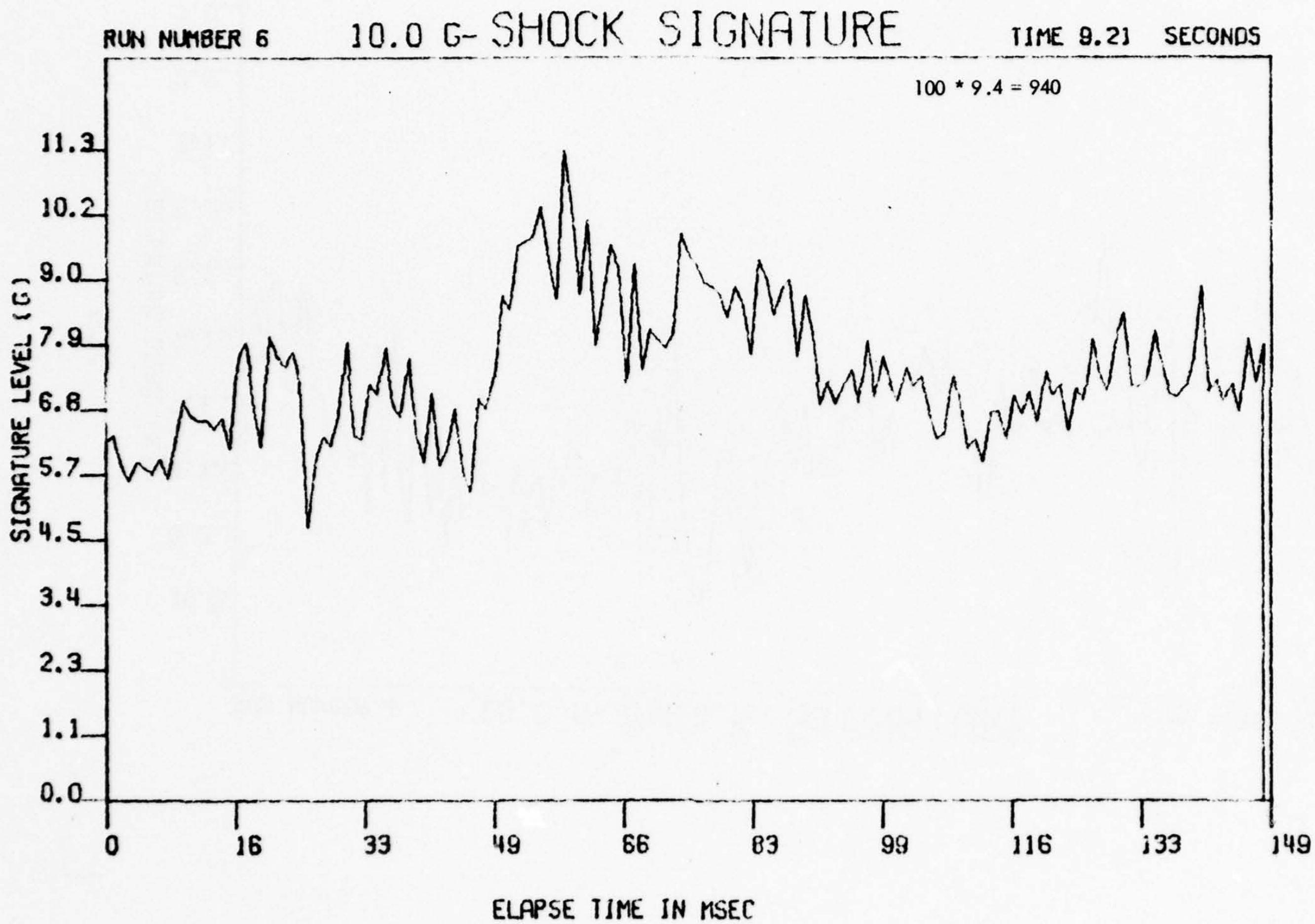
219

221

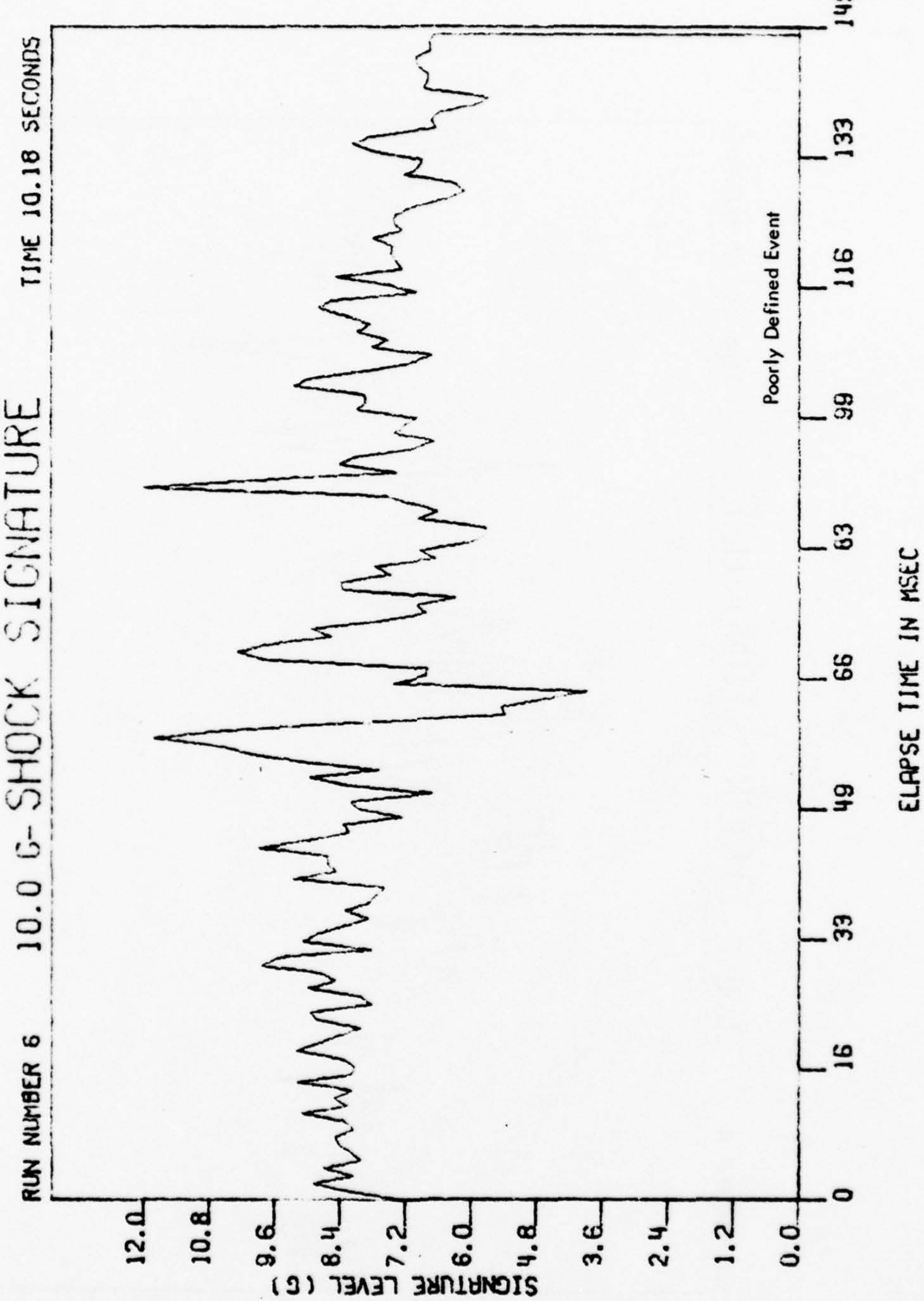

RUN NUMBER 6
10.0 G- SHOCK SIGNATURE
TIME 3.53 SECONDS
SIGNATURE LEVEL (G)
11.6
10.4
9.3
8.1
6.9
5.8
4.6
3.5
2.3
1.2
0.0
0
16
33
49
66
83
99
116
133
149
Poorly Defined Event
ELAPSE TIME IN MSEC

RUN NUMBER 6 10.0 G- SHOCK SIGNATURE TIME 4.39 SECONDS



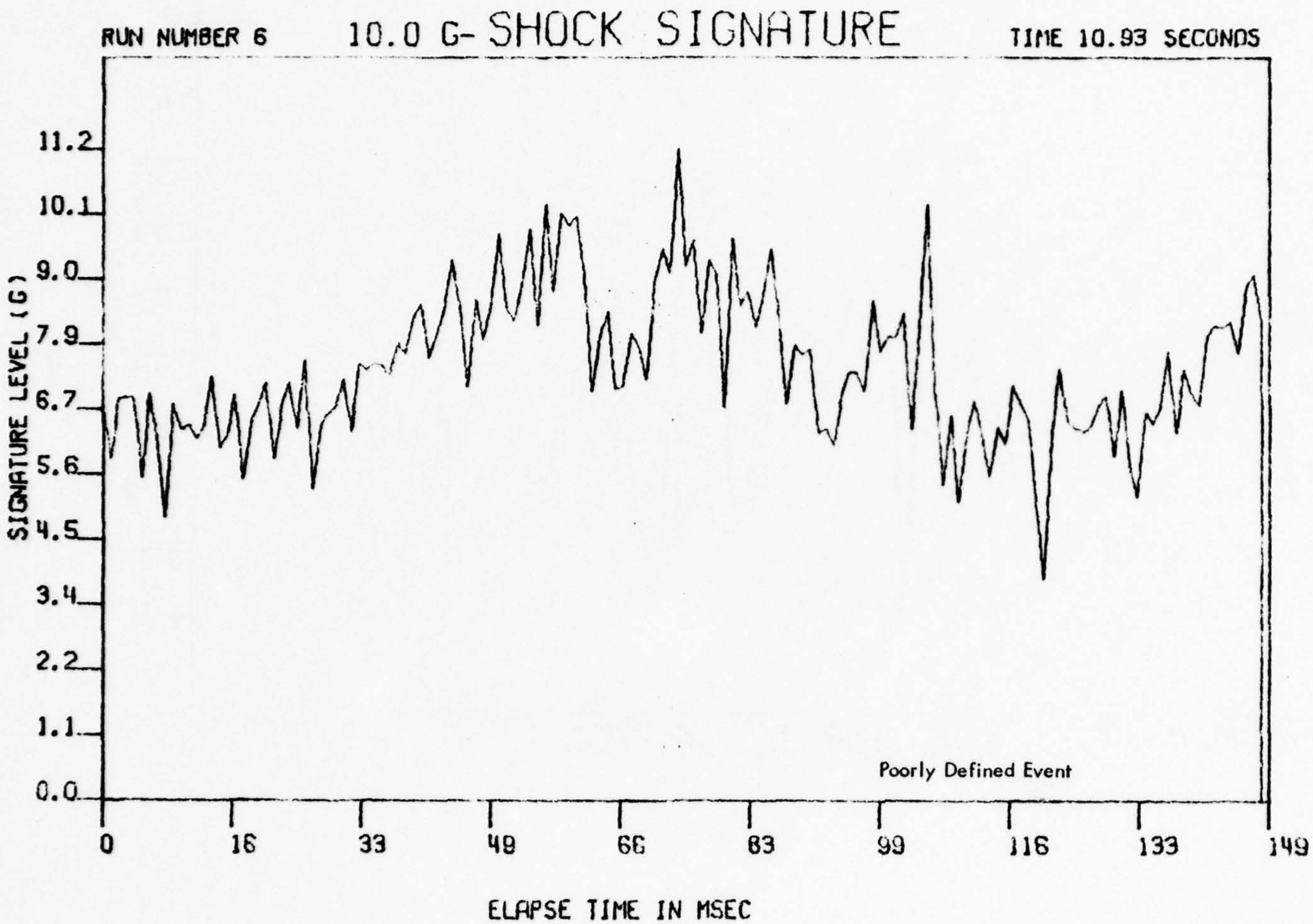

RUN NUMBER 6
10.0 G- SHOCK SIGNATURE
TIME 9.21 SECONDS
100 * 9.4 = 940
SIGNATURE LEVEL (G)
11.3
10.2
9.0
7.9
6.8
5.7
4.5
3.4
2.3
1.1
0.0
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC

292-531 (222)

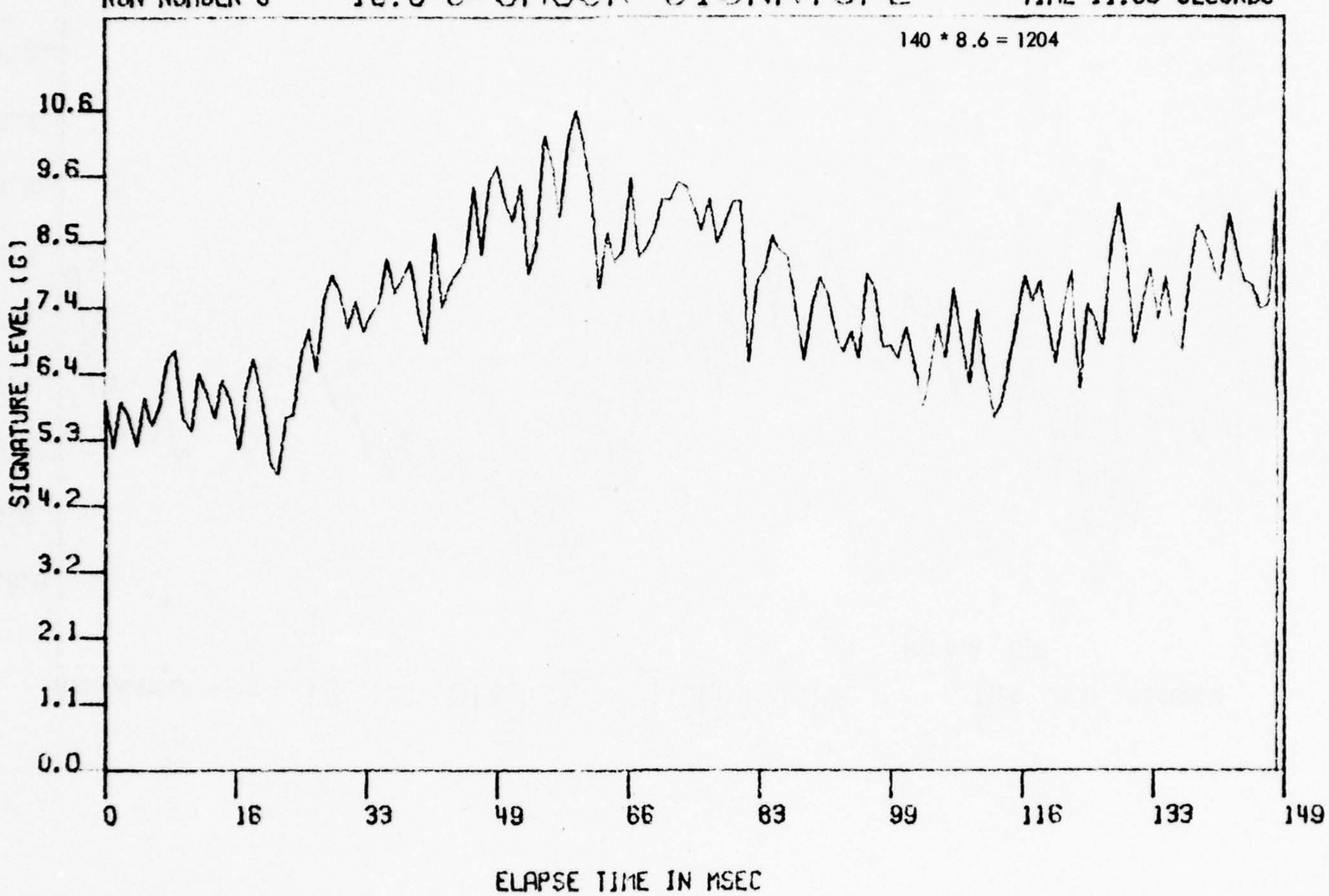


292-531 (223)

225


RUN NUMBER 6
10.0 G- SHOCK SIGNATURE
TIME 10.93 SECONDS
SIGNATURE LEVEL (G)
11.2
10.1
9.0
7.9
6.7
5.6
4.5
3.4
2.2
1.1
0.0
Poorly Defined Event
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC

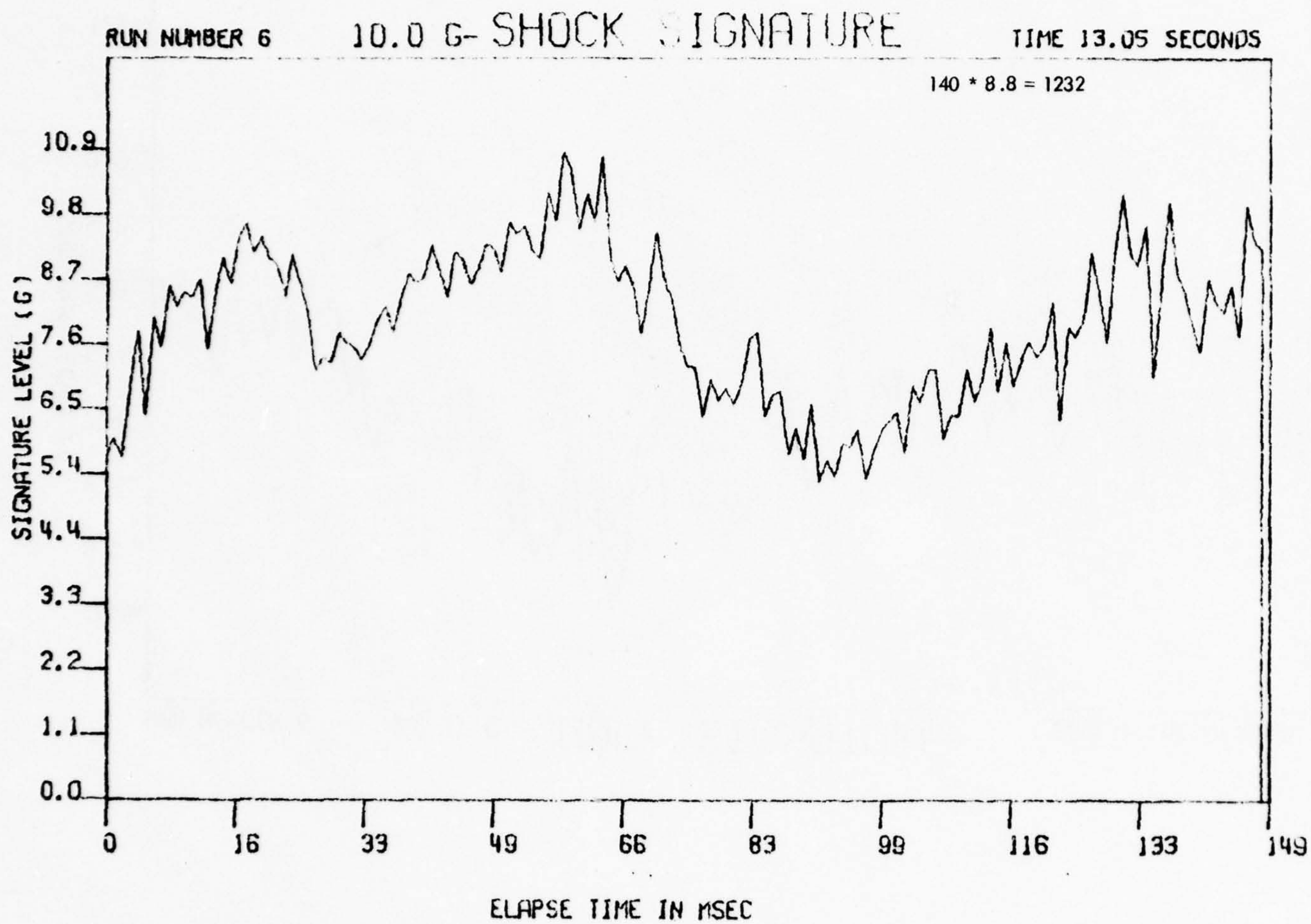
RUN NUMBER 6 10.0 G- SHOCK SIGNATURE TIME 11.85 SECONDS

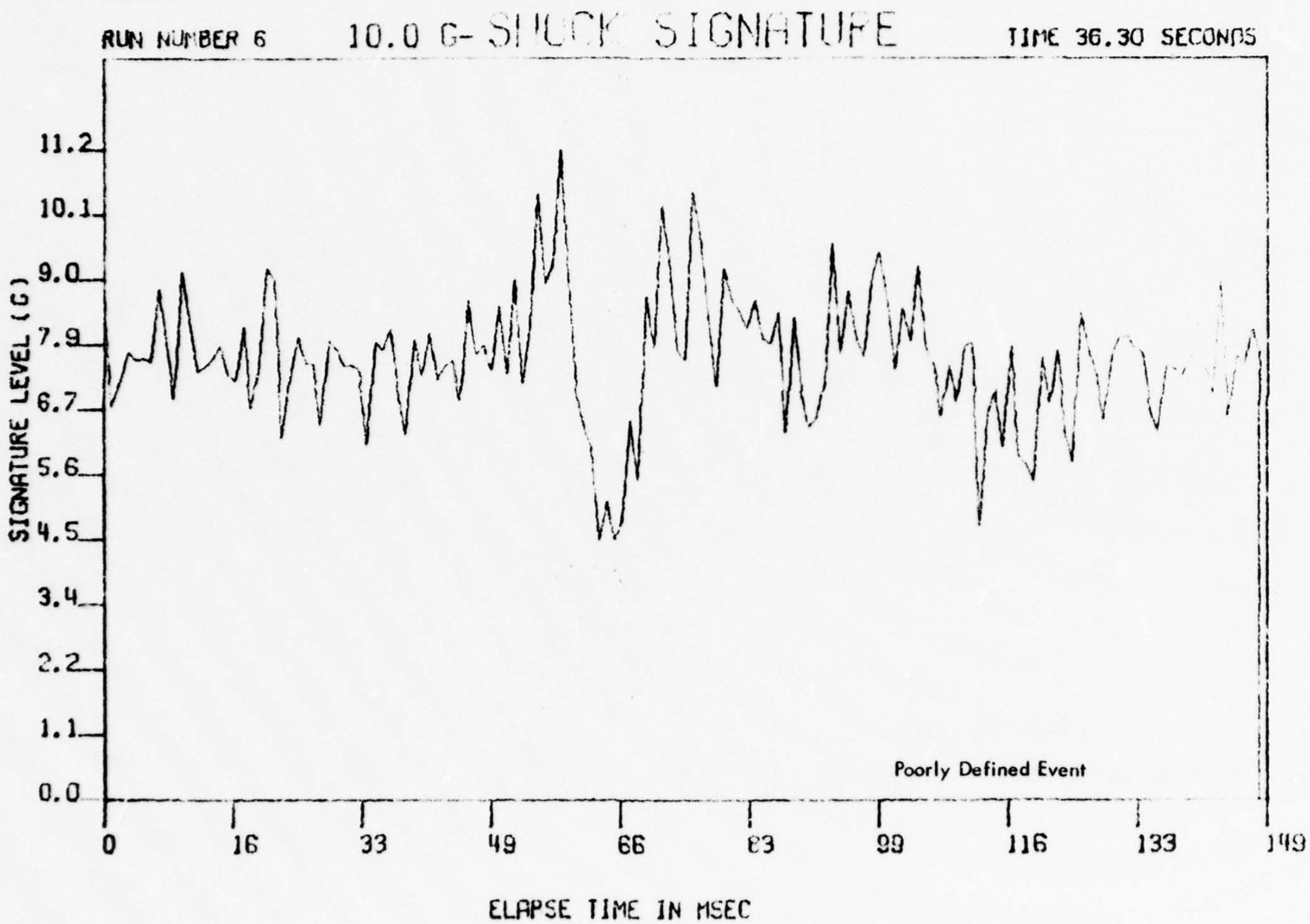


292-531

225

227

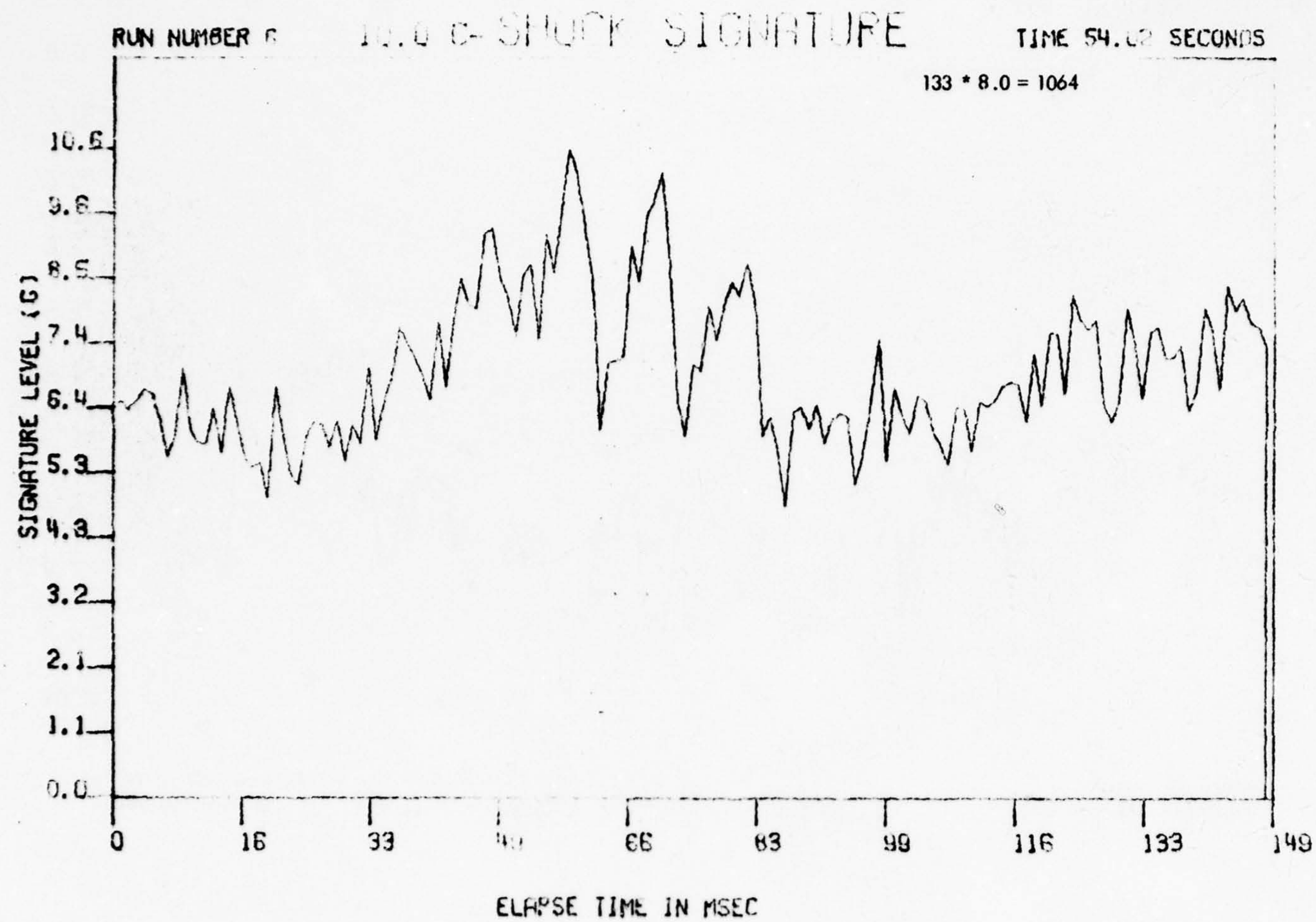

RUN NUMBER 6
10.0 G- SHOCK SIGNATURE
TIME 13.05 SECONDS
140 * 8.8 = 1232
SIGNATURE LEVEL (G)
10.9
9.8
8.7
7.6
6.5
5.4
4.4
3.3
2.2
1.1
0.0
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC

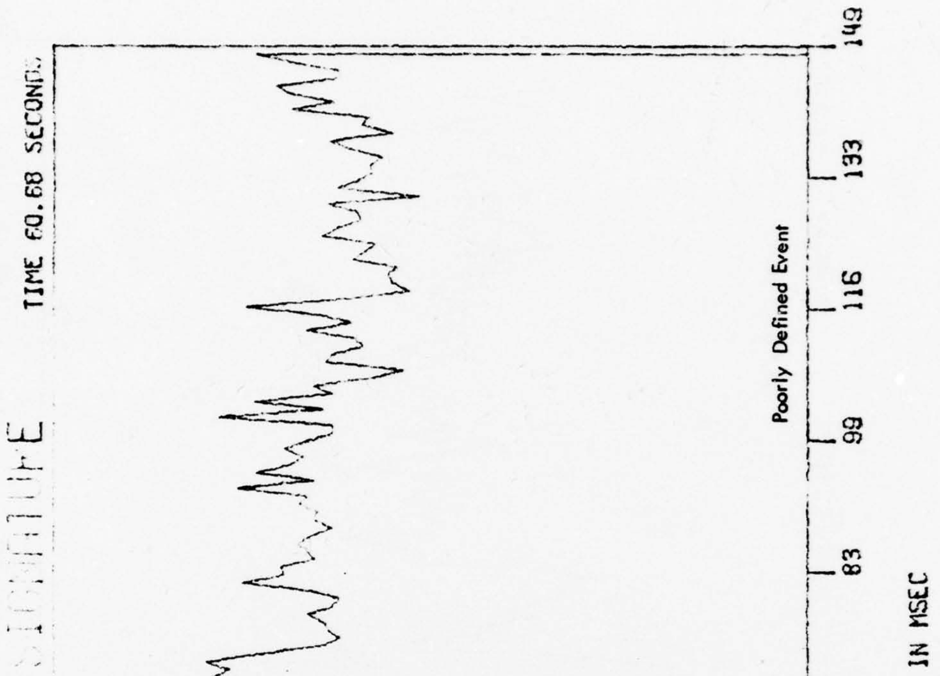

RUN NUMBER 6
10.0 G- SHOCK SIGNATURE
TIME 36.30 SECONDS
SIGNATURE LEVEL (G)
11.2
10.1
9.0
7.9
6.7
5.6
4.5
3.4
2.2
1.1
0.0
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC
Poorly Defined Event

B-38

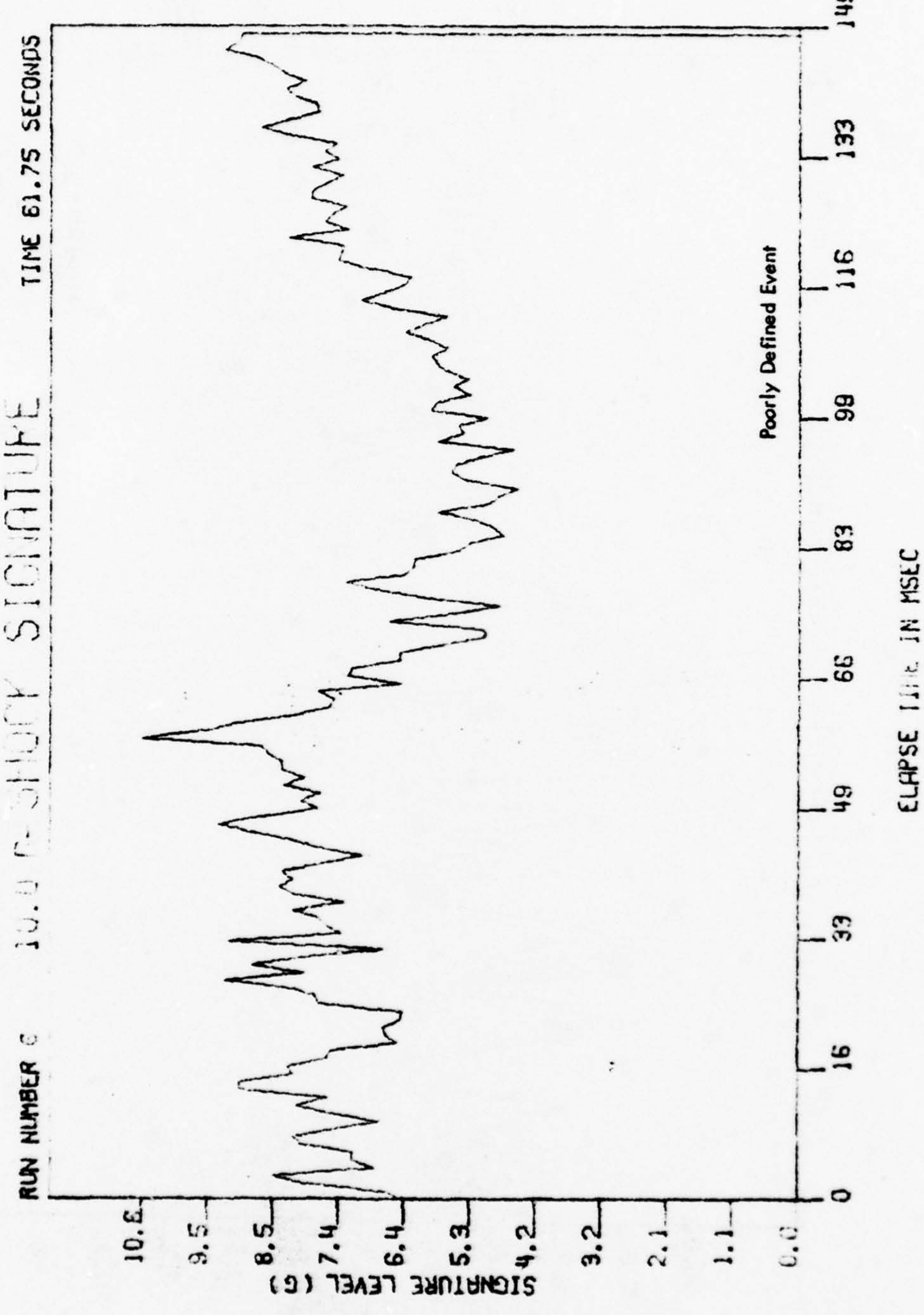
292-531 (228)

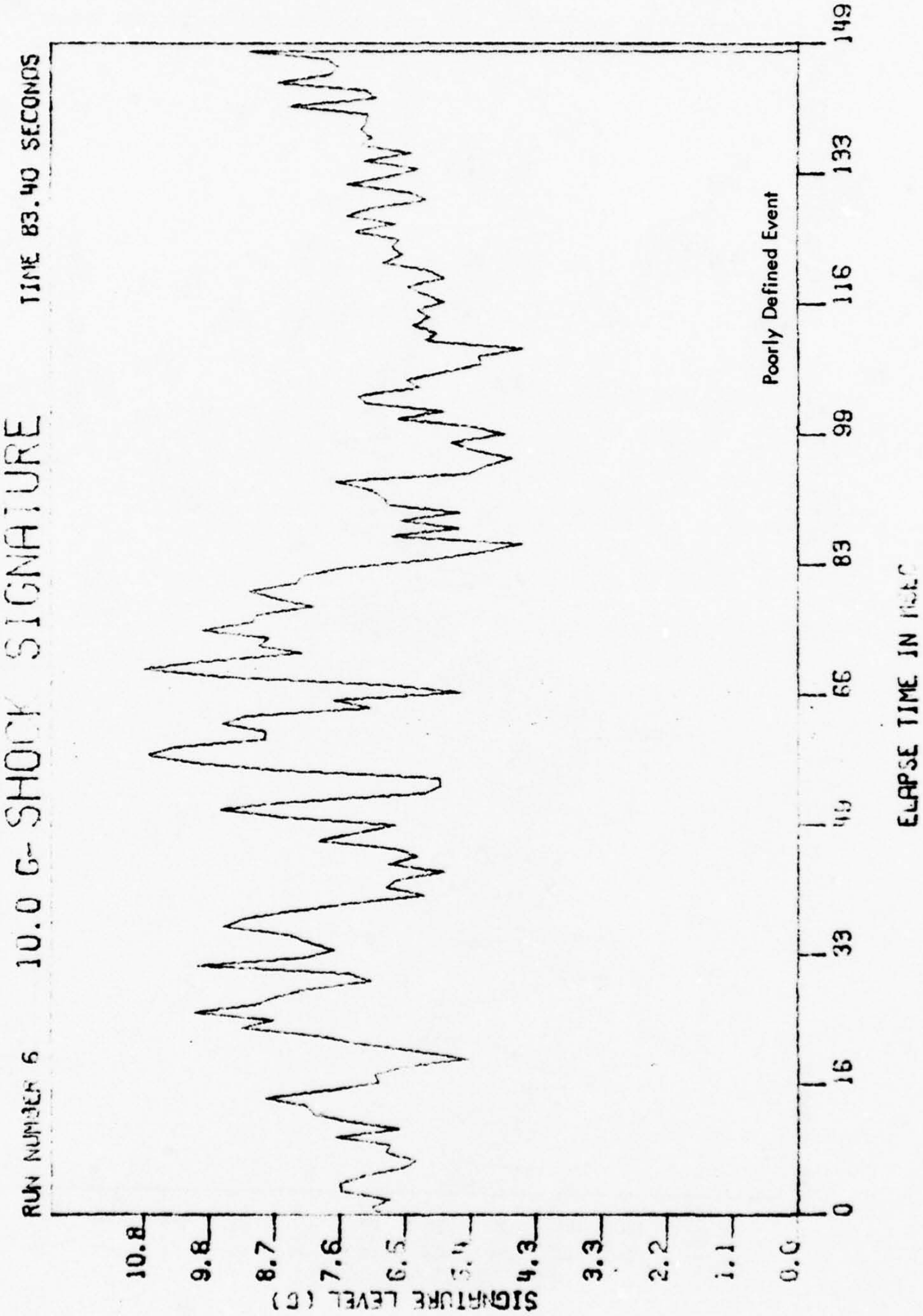
230


RUN NUMBER 6
10.0 G-SHOCK SIGNATURE
TIME 54.02 SECONDS
133 * 8.0 = 1064
SIGNATURE LEVEL (G)
10.6
9.6
8.5
7.4
6.4
5.3
4.3
3.2
2.1
1.1
0.0
0
16
33
66
83
99
116
133
149
ELAPSE TIME IN MSEC

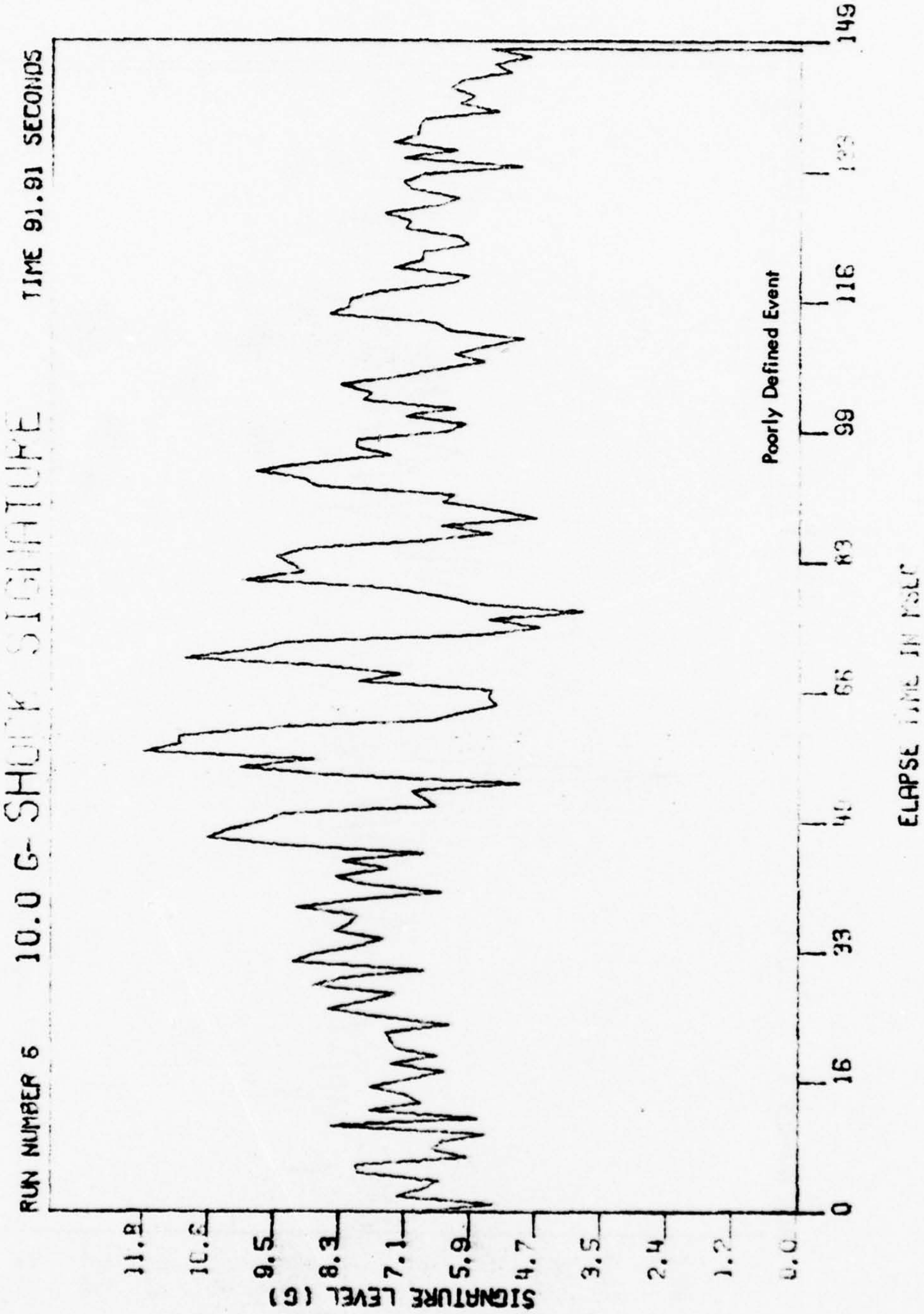

RUN NUMBER 6
10.0 G- SH
TIME 60.68 SECOND
Poorly Defined Event
SIGNATURE LEVEL (G)
10.2
8.2
7.2
6.1
5.1
4.1
3.1
2.0
1.0
0.0
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC

292-531 230


RUN NUMBER 6
SHORT SIGNATURE
TIME 61.75 SECONDS
Poorly Defined Event
ELAPSE TIME IN MSEC
SIGNATURE LEVEL (G)
0
16
33
49
66
83
99
116
133
149
10.6
9.5
8.5
7.4
6.4
5.3
4.2
3.2
2.1
1.1
0.0

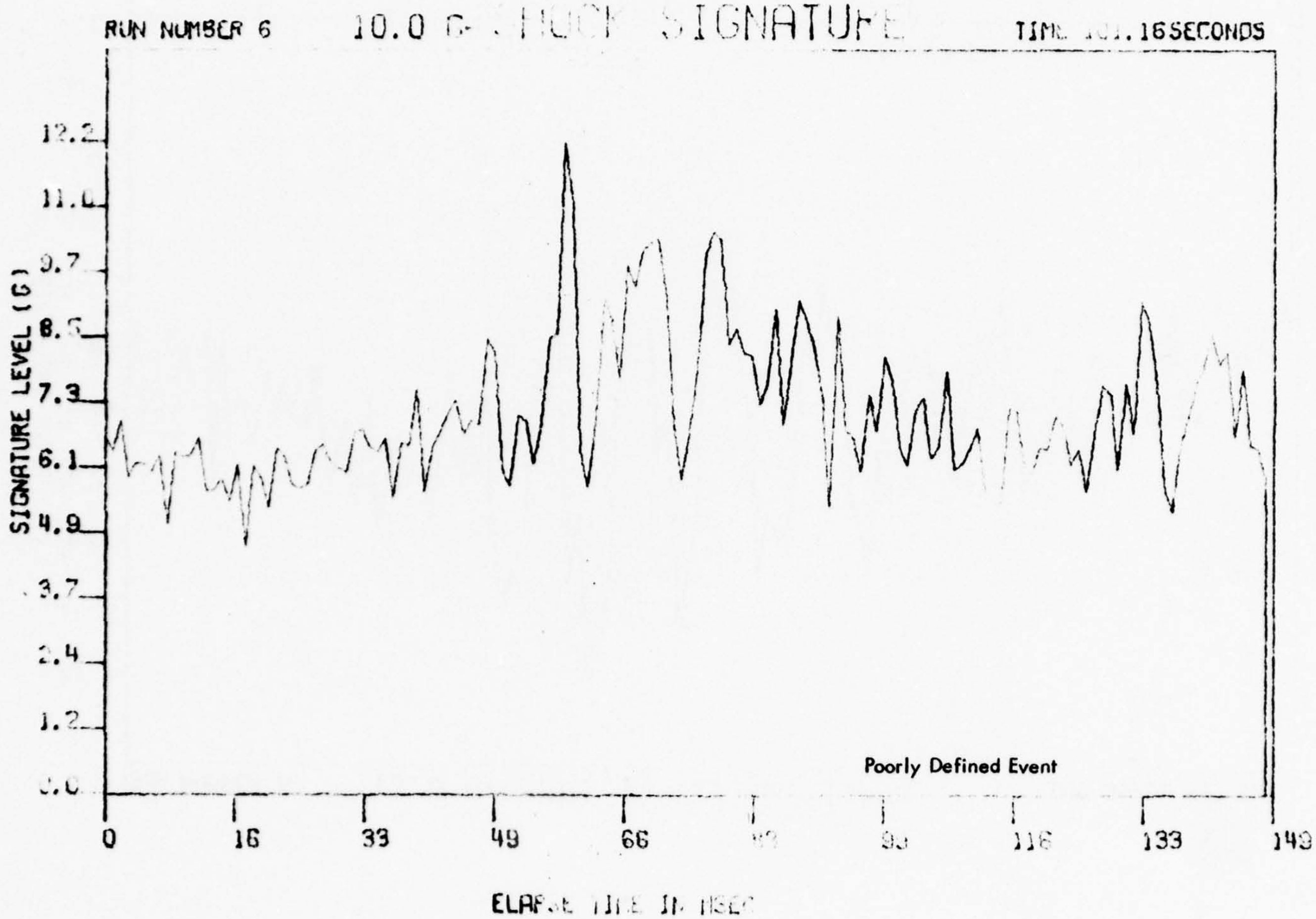


RUN NUMBER 6
10.0 G-SHOCK SIGNATURE
TIME 83.40 SECONDS
Poorly Defined Event
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC
10.8
9.8
8.7
7.6
6.5
4.3
3.3
2.2
1.1
0.0
SIGNATURE LEVEL (G)



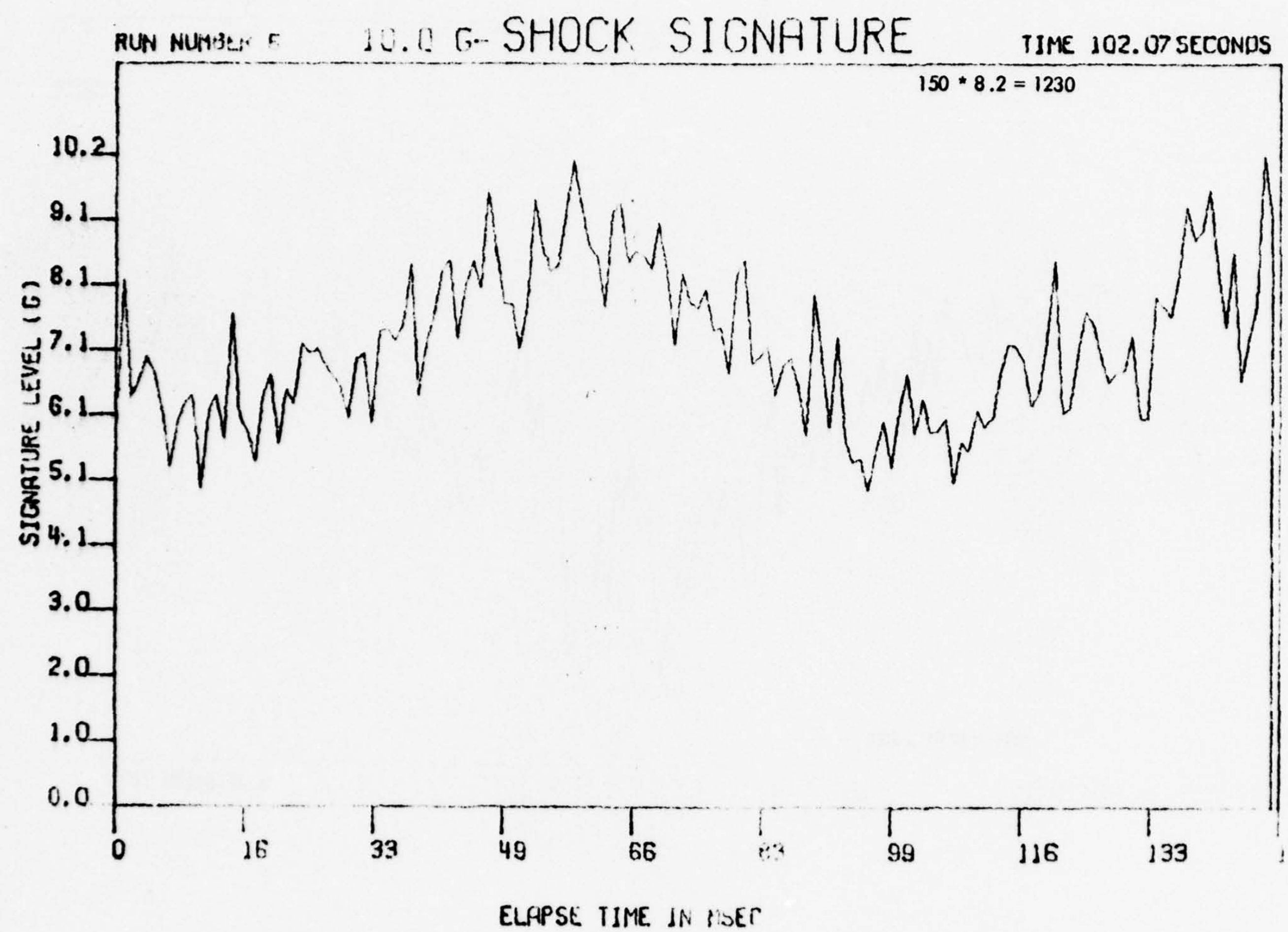
292-531 (233)

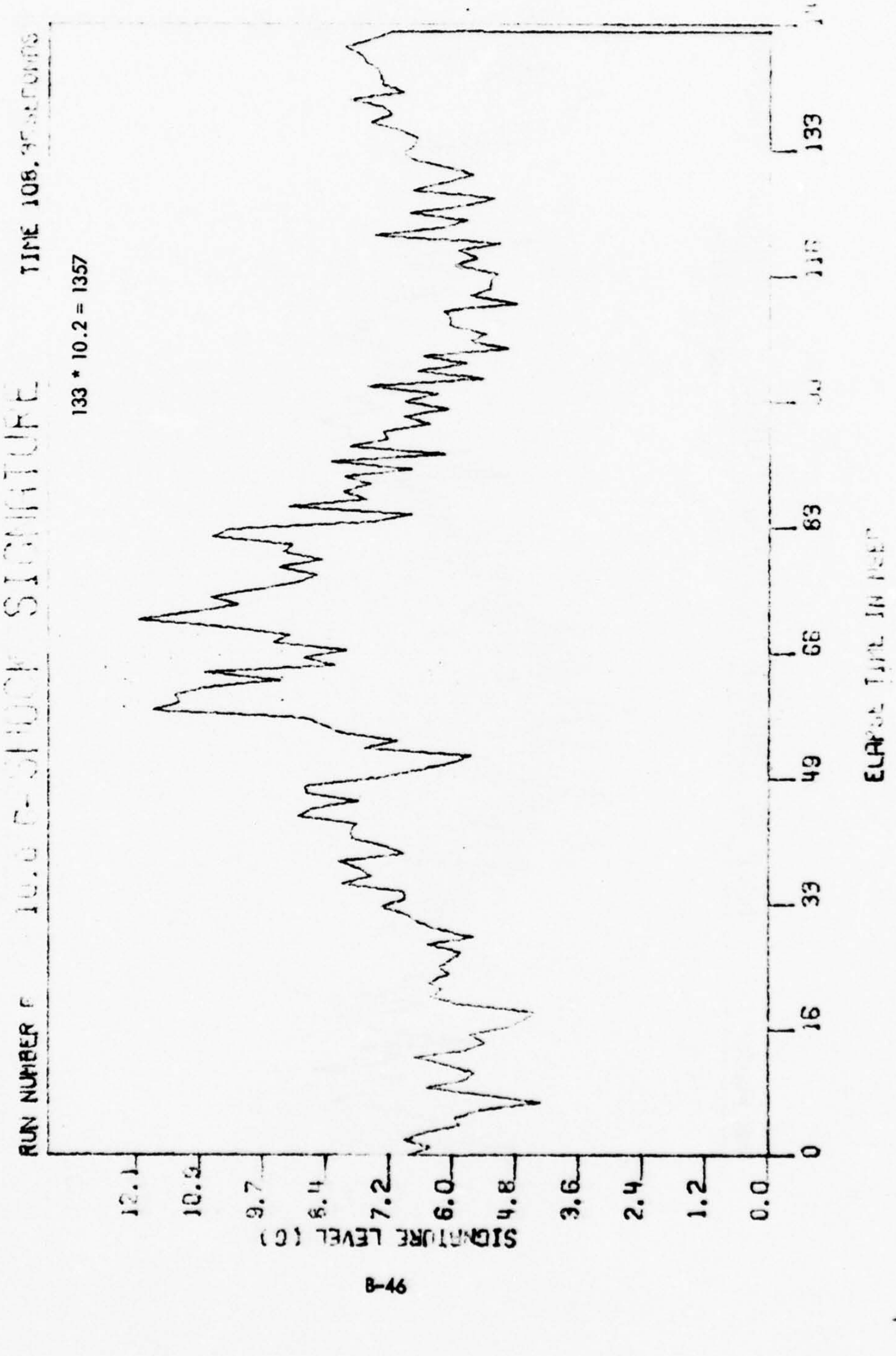
235



292-531 (234)

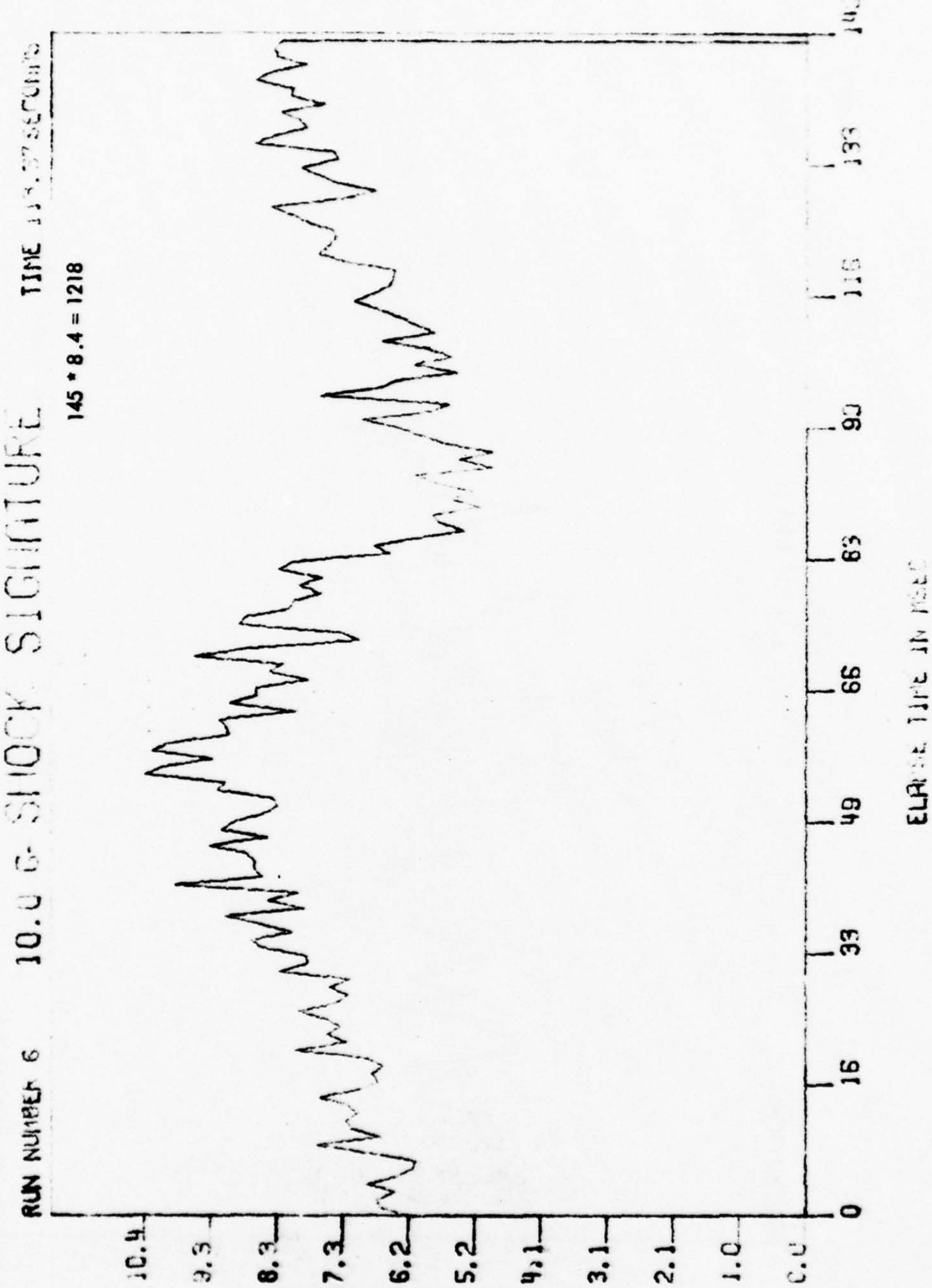
(236)


SHOCK SIGNATURE
TIME 102.07 SECONDS
150 * 8.2 = 1230
SIGNATURE LEVEL (G)
10.2
9.1
8.1
7.1
6.1
5.1
4.1
3.0
2.0
1.0
0.0
0
16
33
49
66
99
116
133
ELAPSE TIME IN

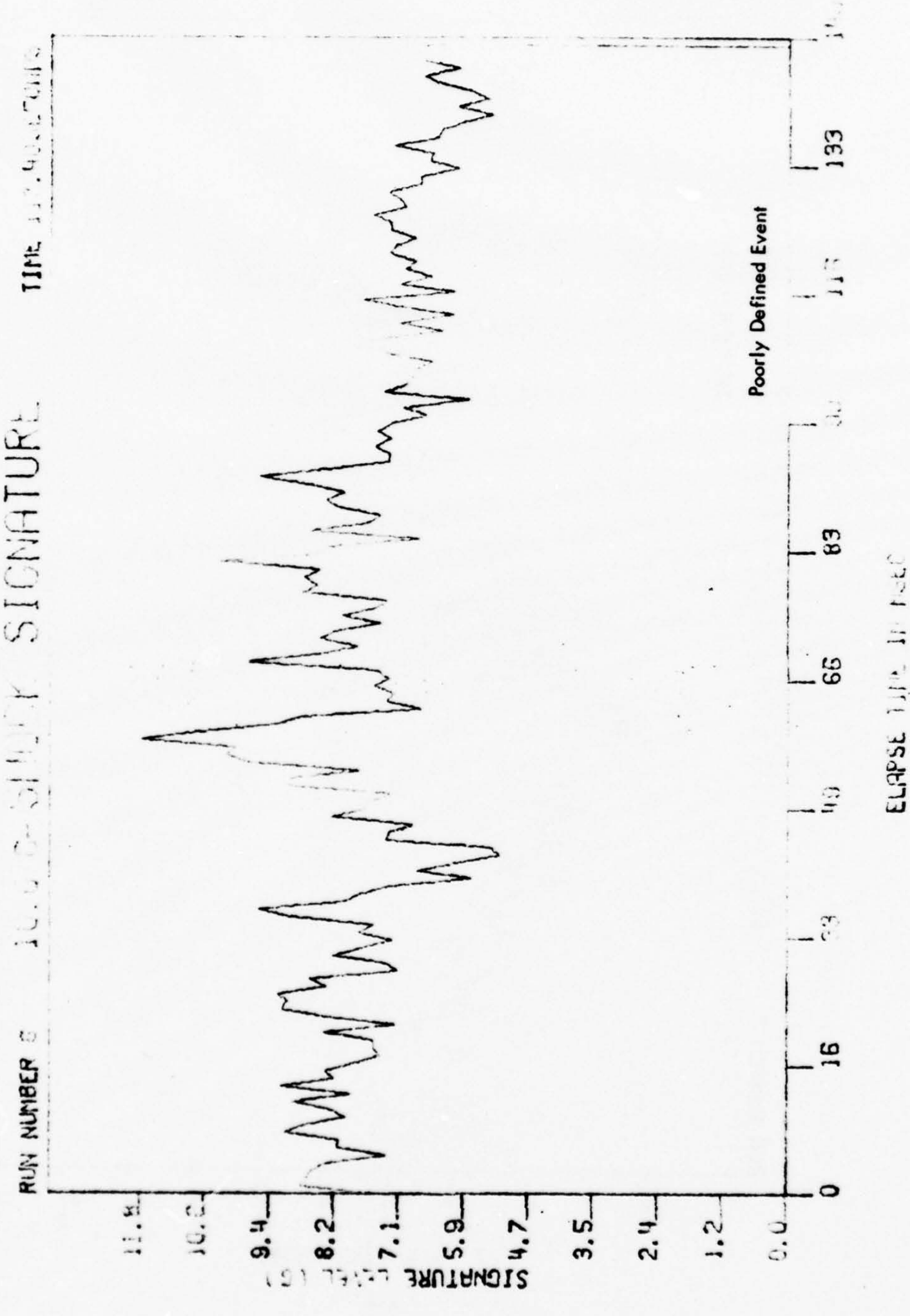


292-531 (236)

238


RUN NUMBER 6
10.0 G SHOCK SIGNATURE
TIME
145 * 8.4 = 1218
SIGNATURE LEVEL (G)
10.4
9.3
8.3
7.3
6.2
5.2
4.1
3.1
2.1
1.0
0.0
0
16
33
49
66
83
99
116
133
ELAPSE TIME IN MSEC

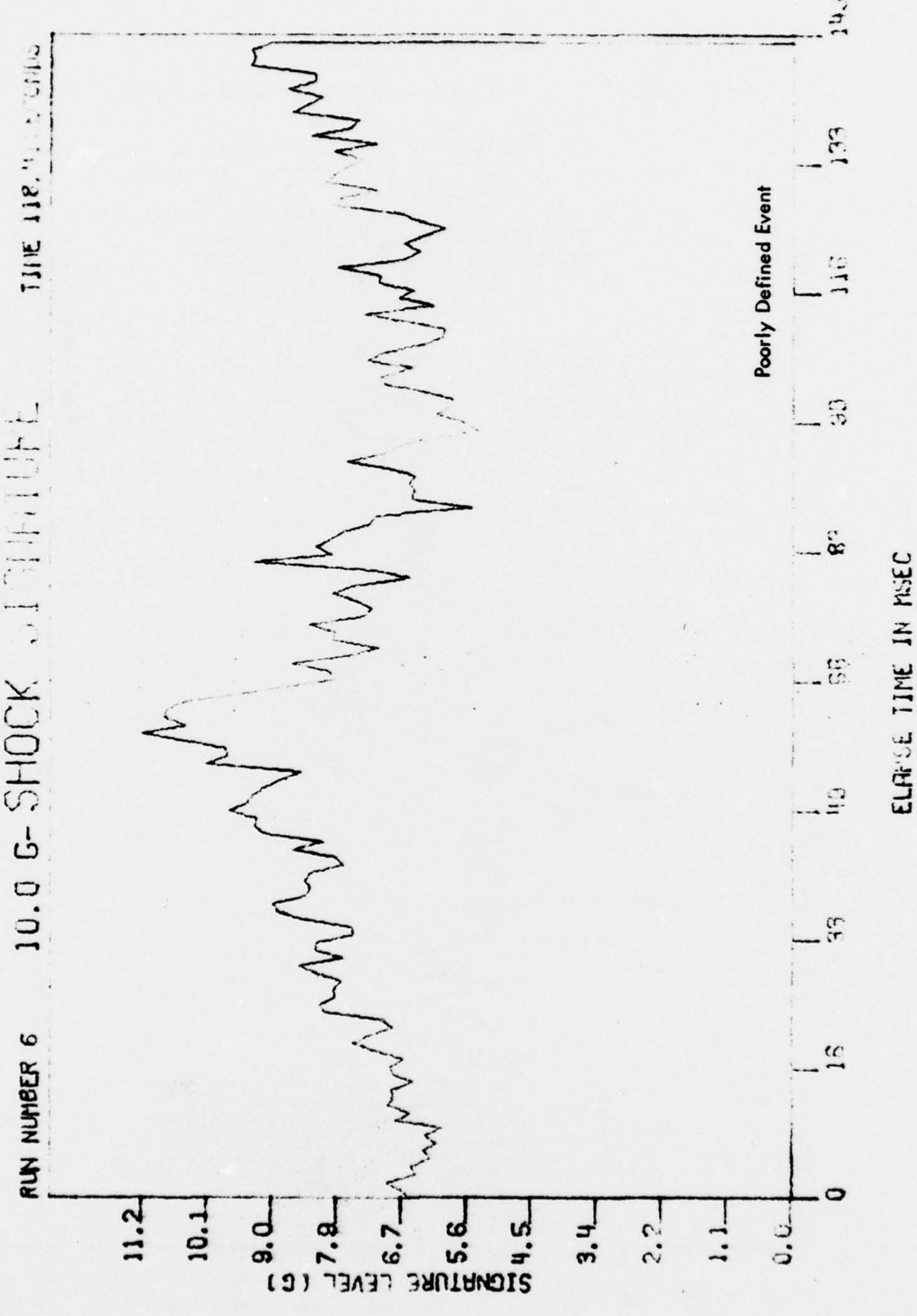
B-47

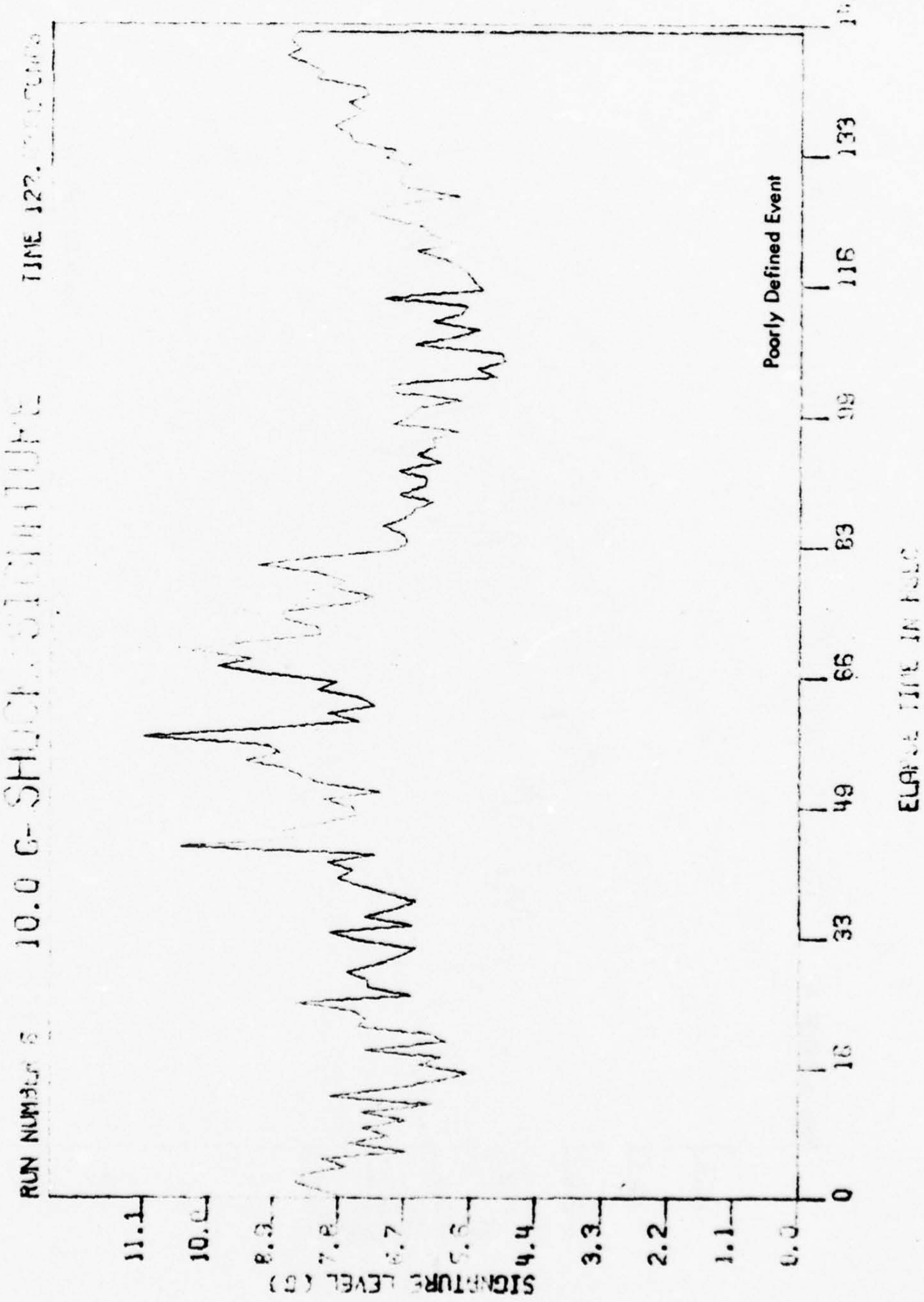


292-531

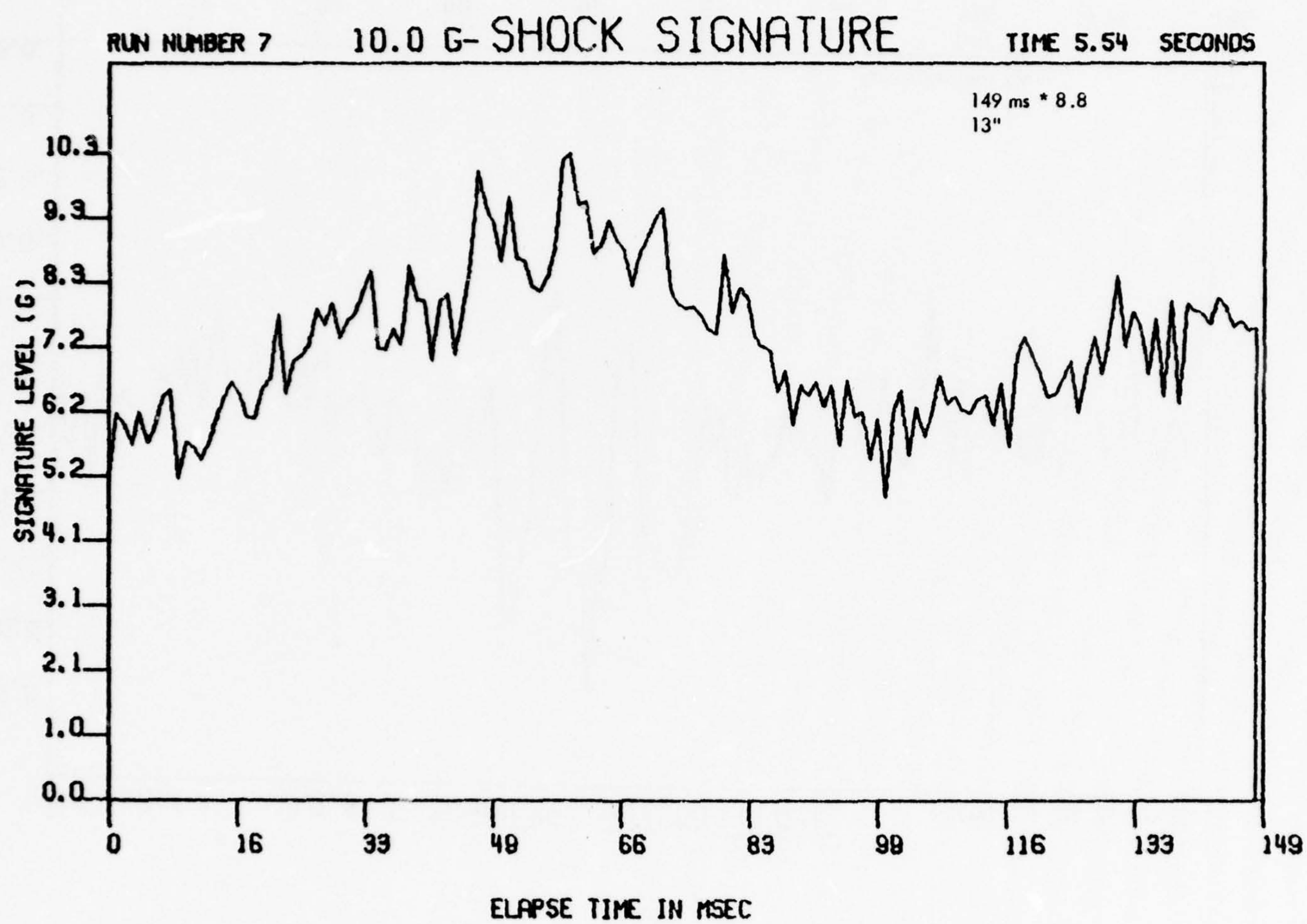
238

240

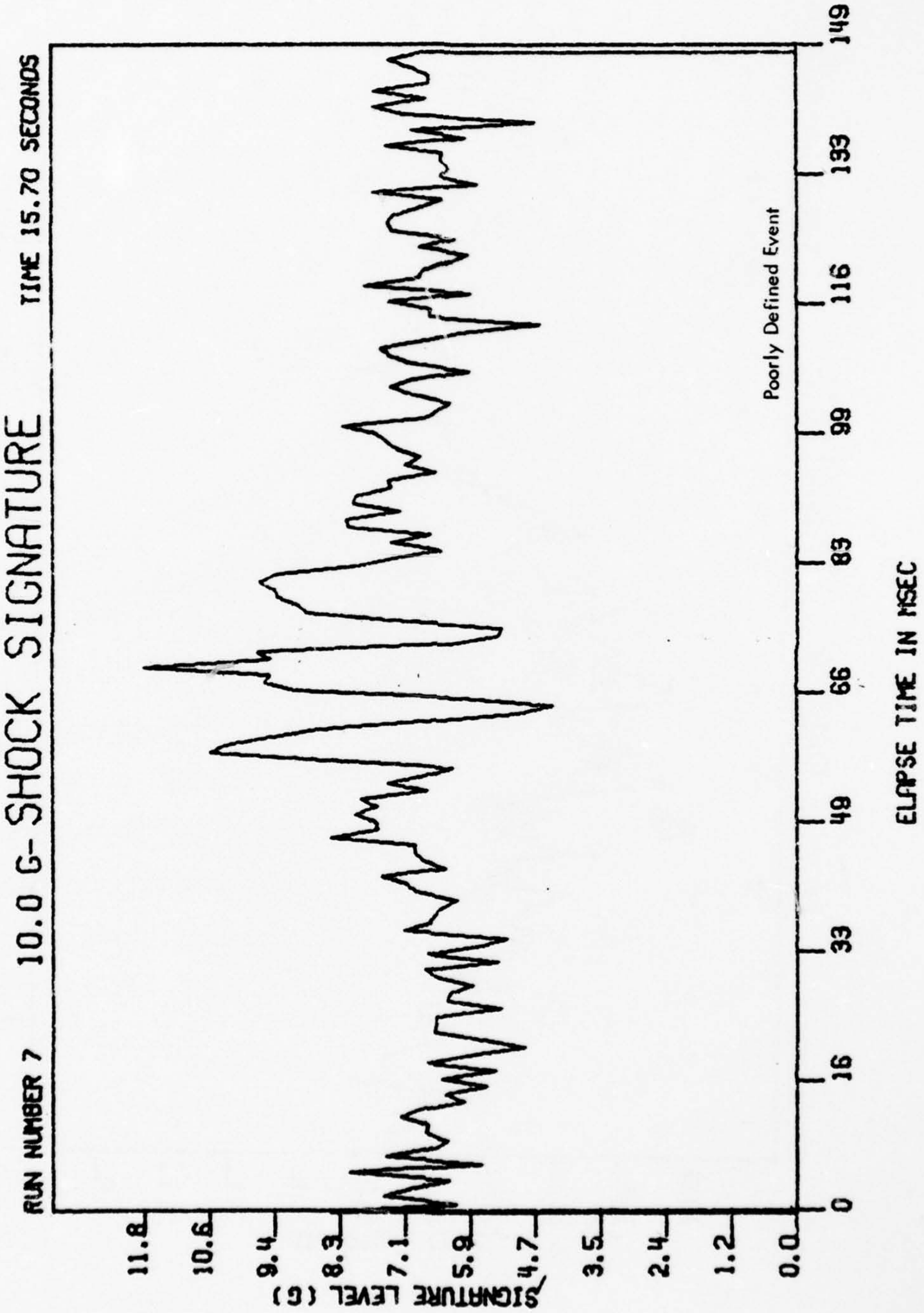

RUN NUMBER 6
10.0 G- SHOCK
SIGNATURE LEVEL (G)
11.2
10.1
9.0
7.8
6.7
5.6
4.5
3.4
2.2
1.1
0.0
0
16
33
49
66
83
116
133
Poorly Defined Event
ELAPSE TIME IN MSEC



10.0 G- SHOCK SIGNATURE
Poorly Defined Event
0
16
33
49
66
83
99
116
133
11.1
10.0
7.8
6.7
4.4
3.3
2.2
1.1
0.0



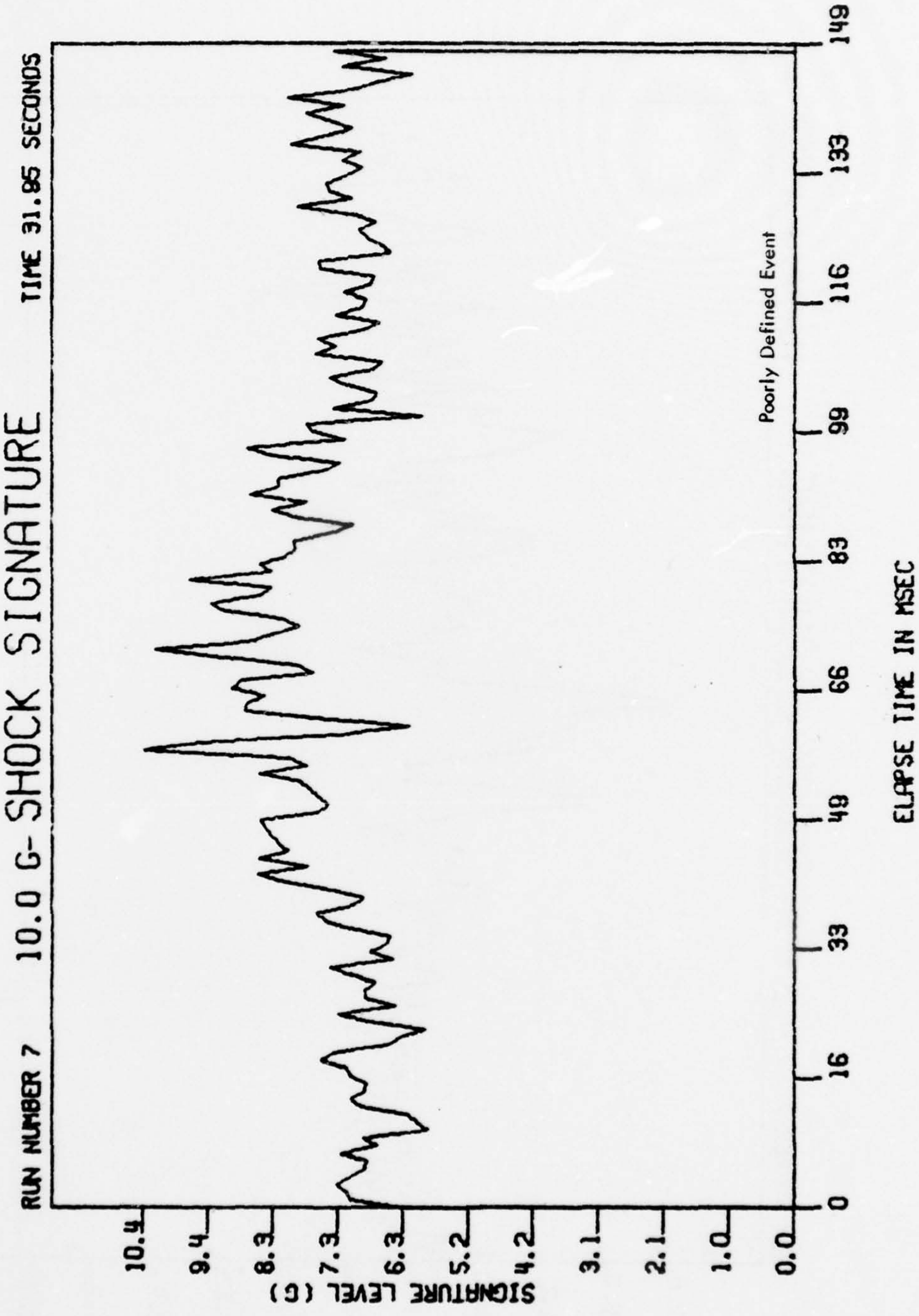
292-531 241 243

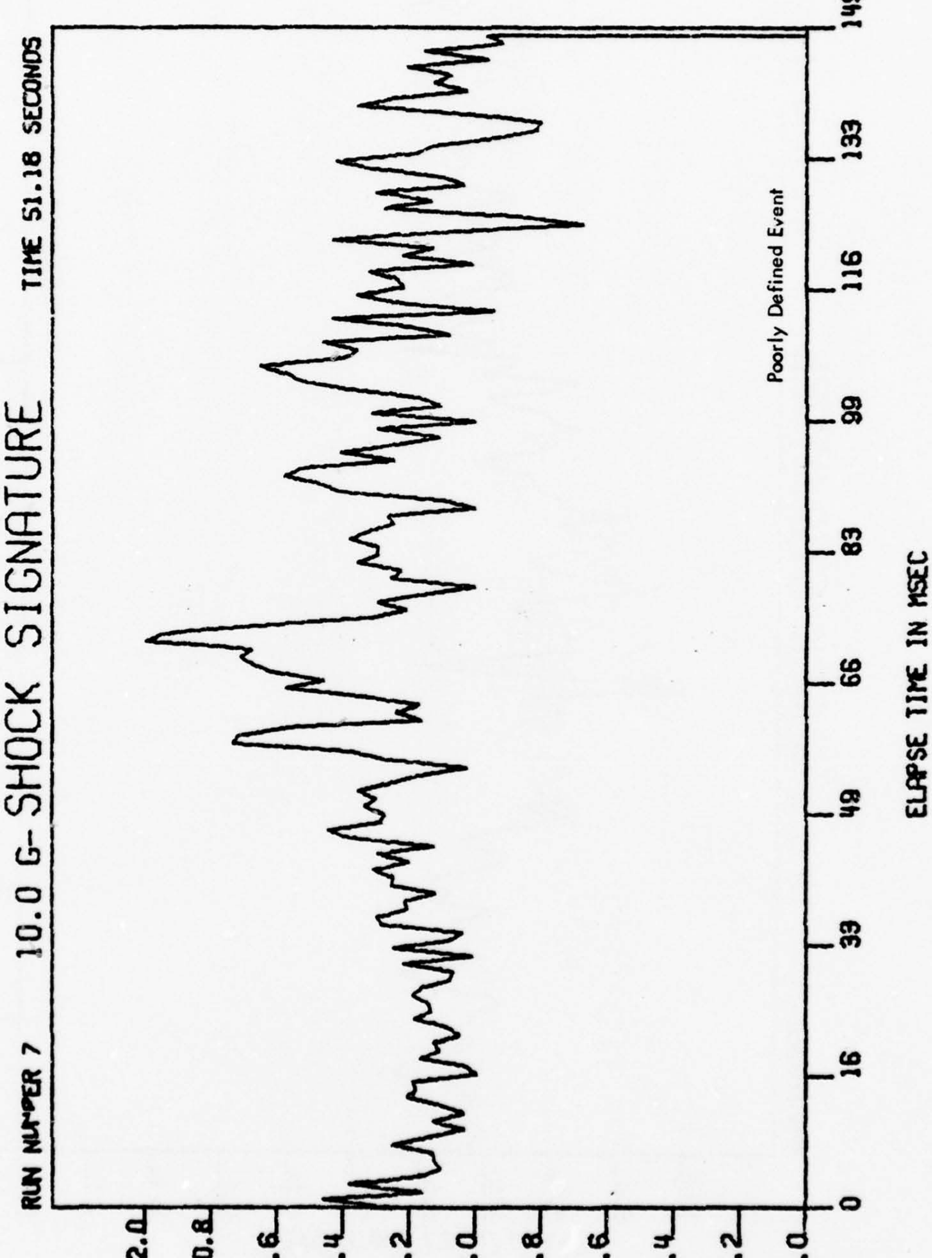


292-531 (242)

244

251

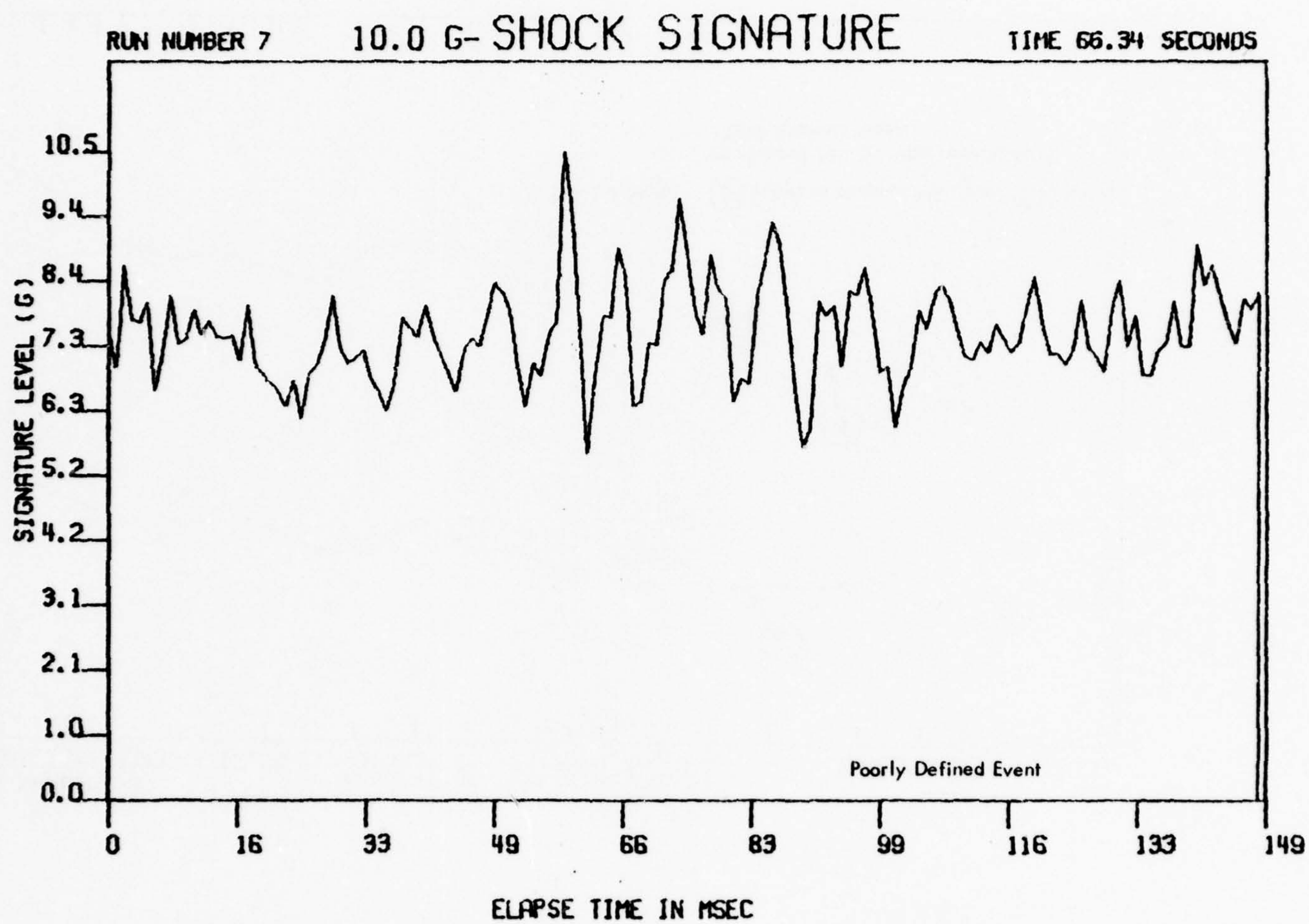

RUN NUMBER 7
10.0 G- SHOCK SIGNATURE
TIME 31.85 SECONDS
Poorly Defined Event
SIGNATURE LEVEL (G)
10.4
9.4
8.3
7.3
6.3
5.2
4.2
3.1
2.1
1.0
0.0
0
16
33
49
66
83
99
116
133
149
ELAPSE TIME IN MSEC



292-531

244

246

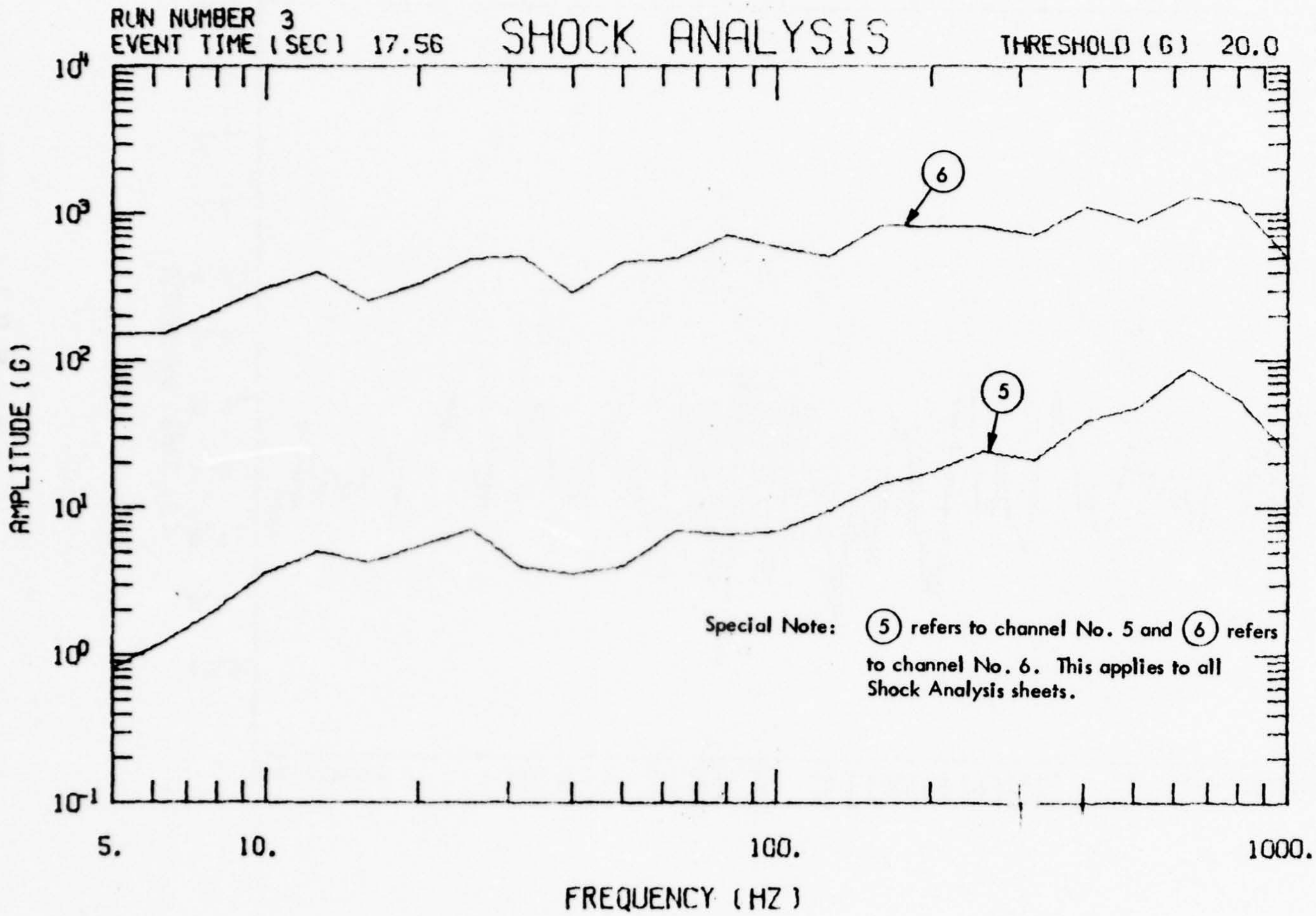


292-531

245

247

251



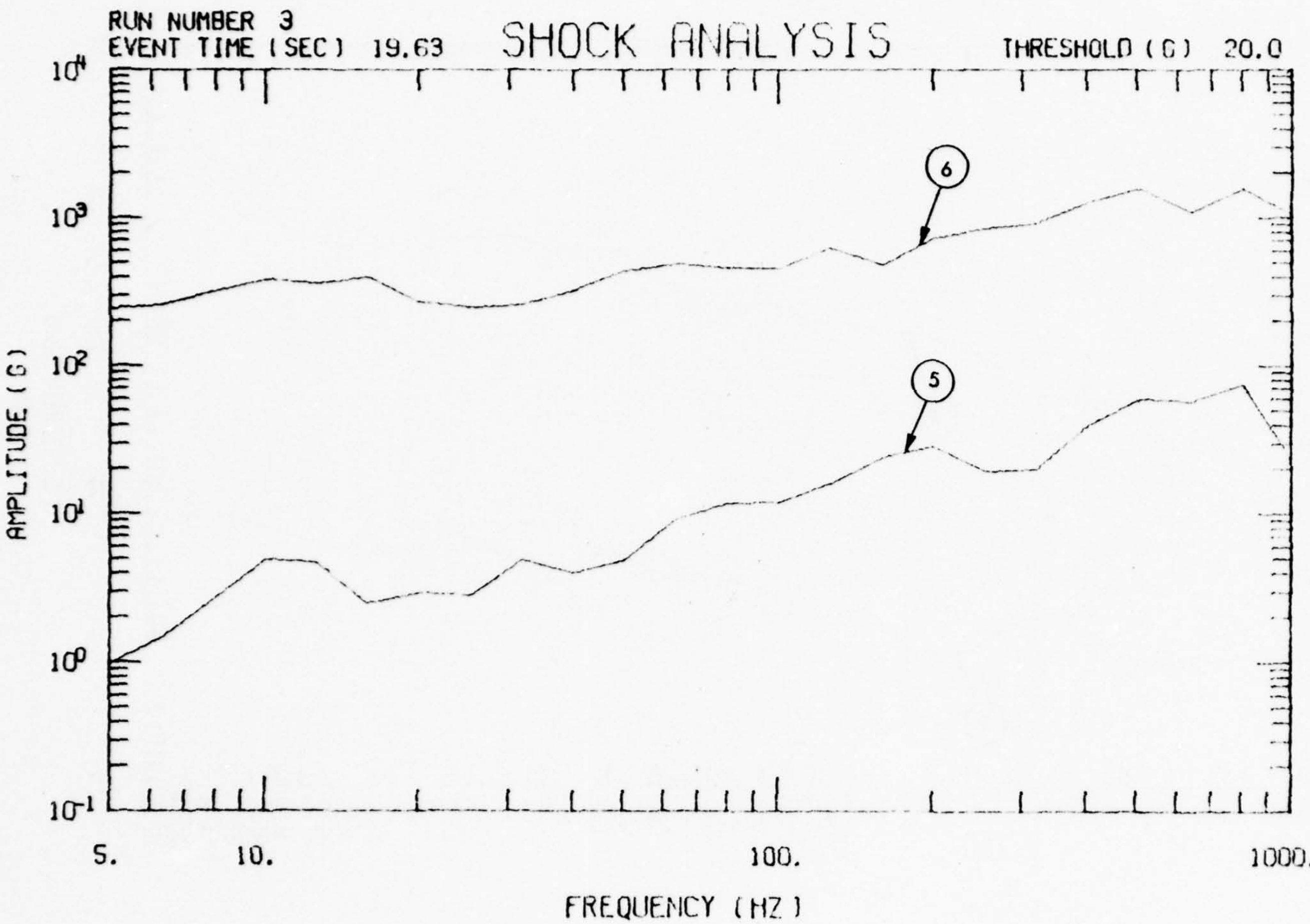
292-531

246

248

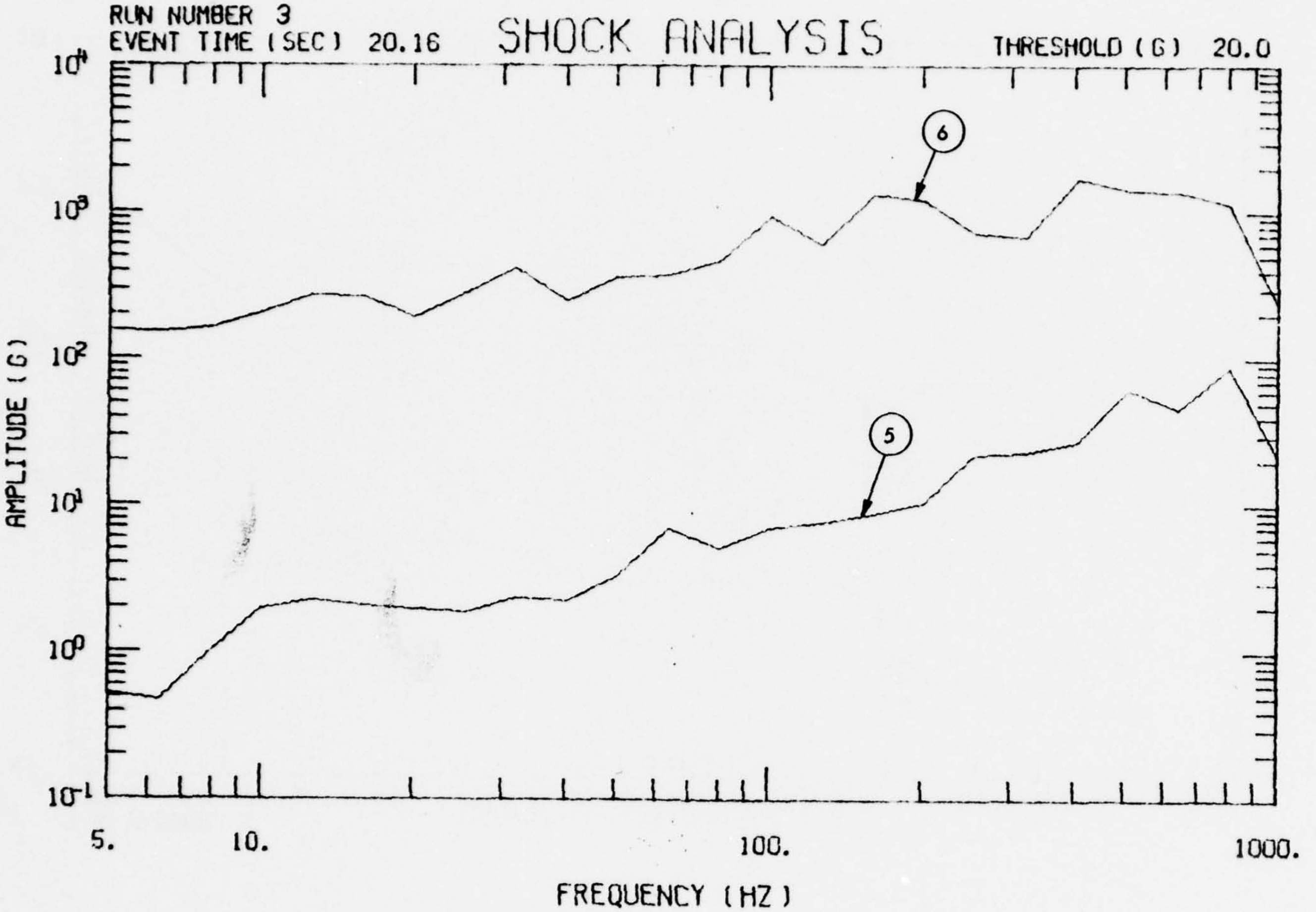
5

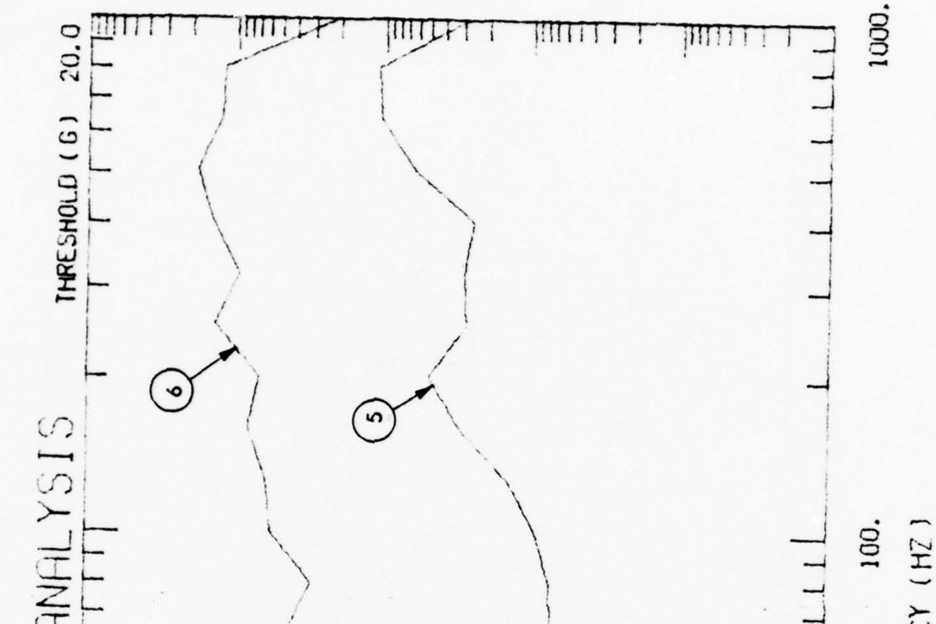
12.27


RUN NUMBER 3
EVENT TIME (SEC) 19.63
SHOCK ANALYSIS
THRESHOLD (G) 20.0
10^4
10^3
10^2
10^1
10^0
10^{-1}
AMPLITUDE (G)
6
5
5.
10.
100.
1000.
FREQUENCY (HZ)

6

12-27


RUN NUMBER 3
EVENT TIME (SEC) 20.16
SHOCK ANALYSIS
THRESHOLD (G) 20.0
AMPLITUDE (G)
10^4
10^3
10^2
10^1
10^0
10^{-1}
6
5
5.
10.
100.
1000.
FREQUENCY (HZ)

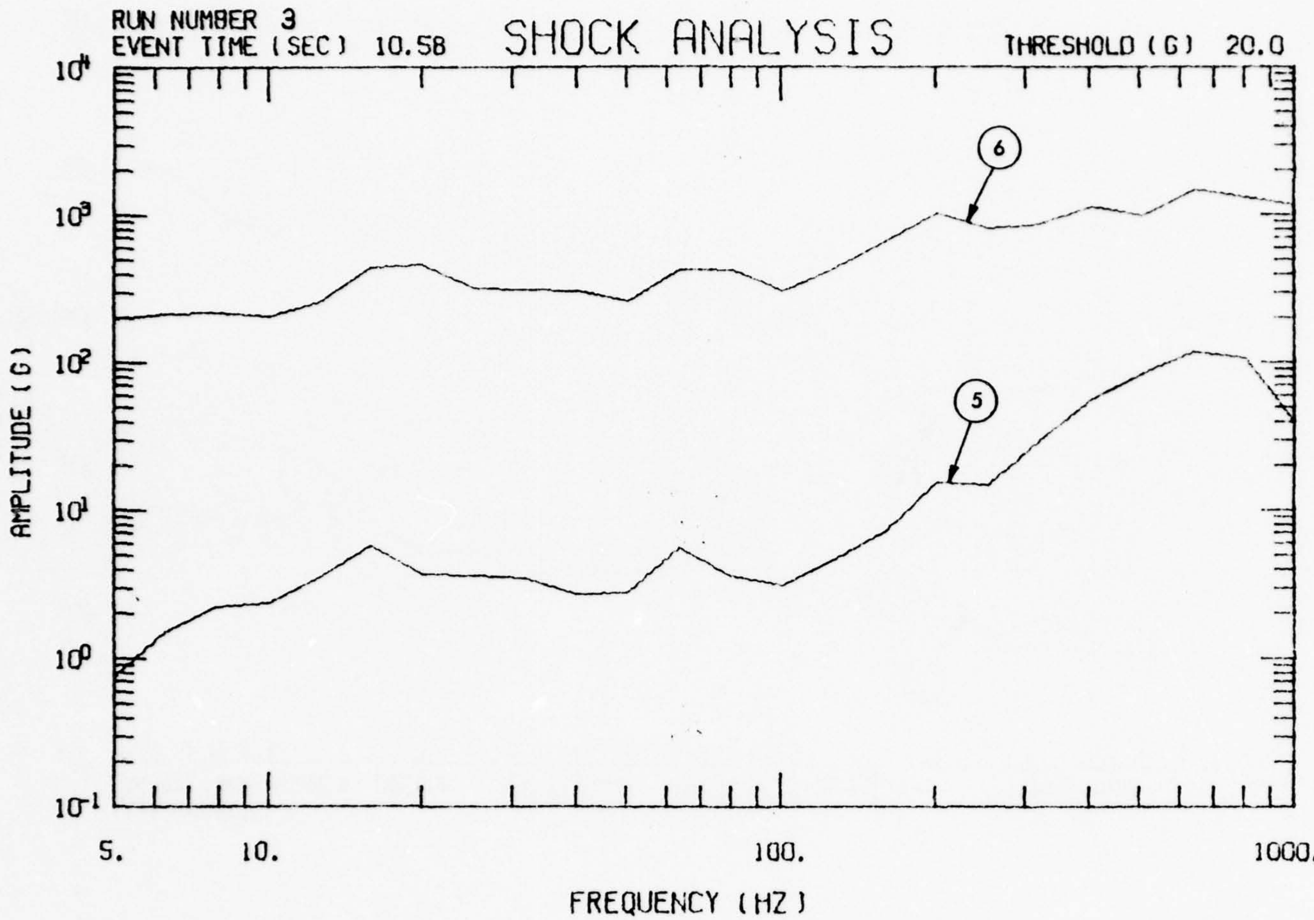


B-59

251

255

12-2-73

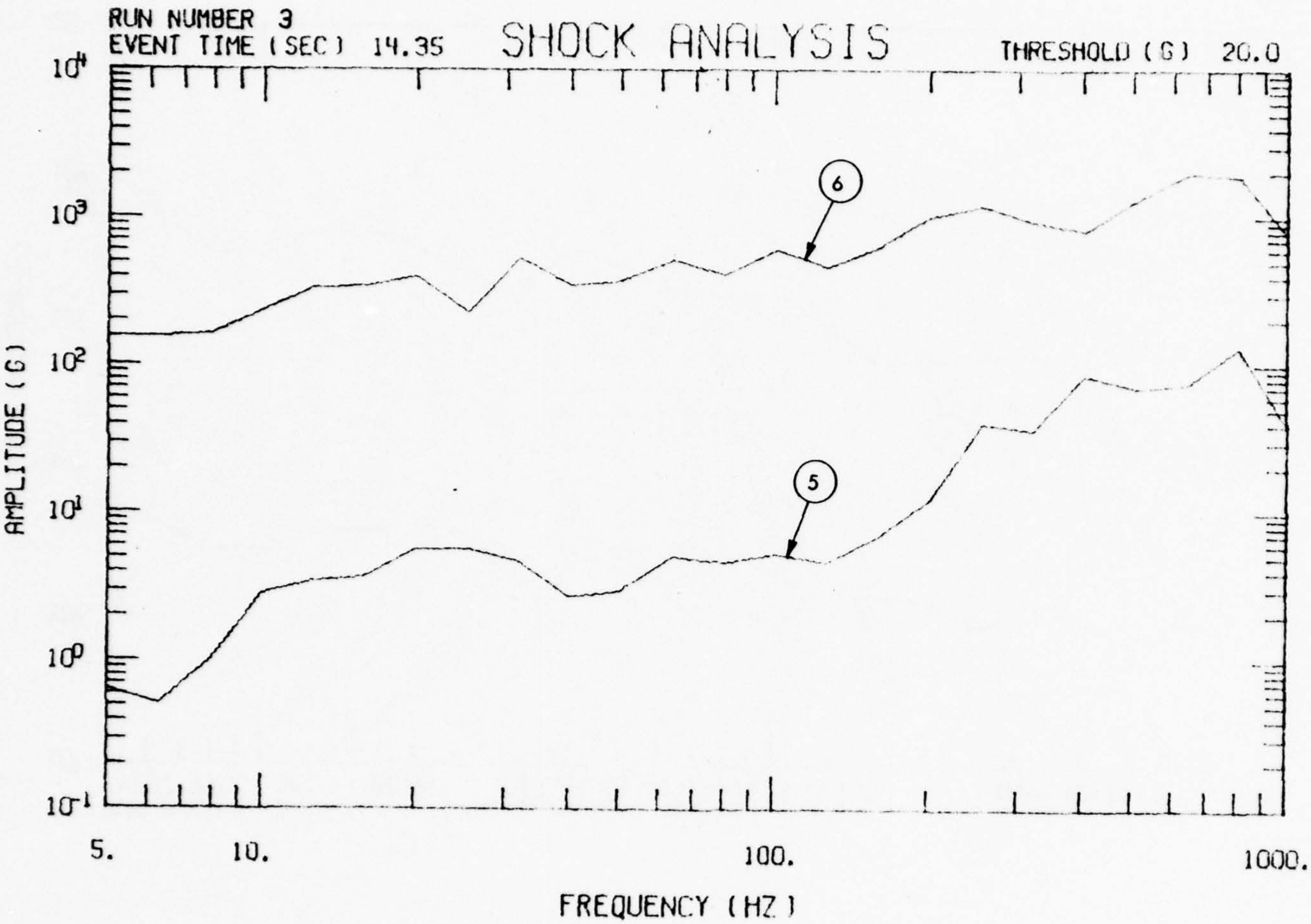


292-531

250

252

10 12-27



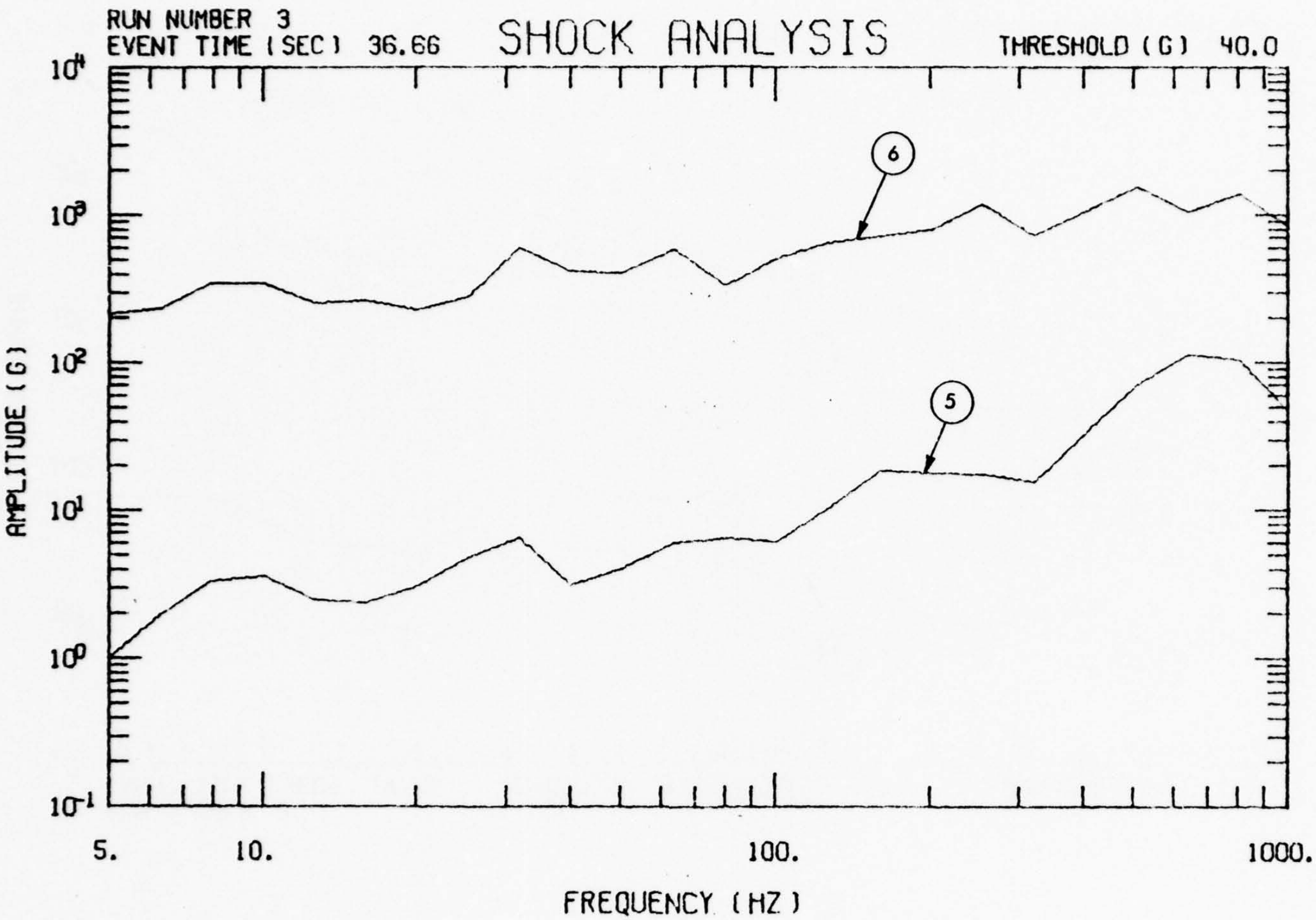
292-531

251

253

257

// 12-29



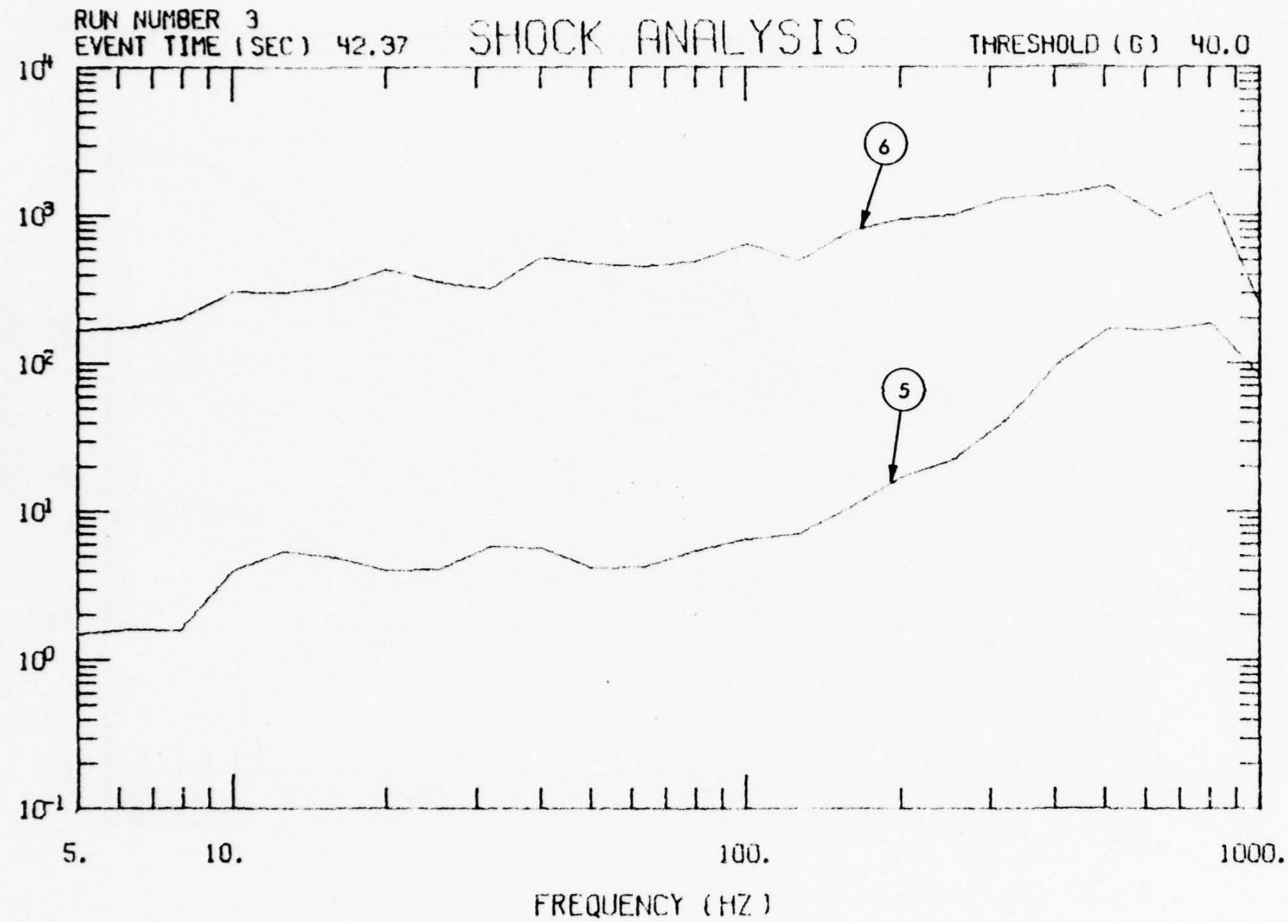
292-531

252

254

13

12-27



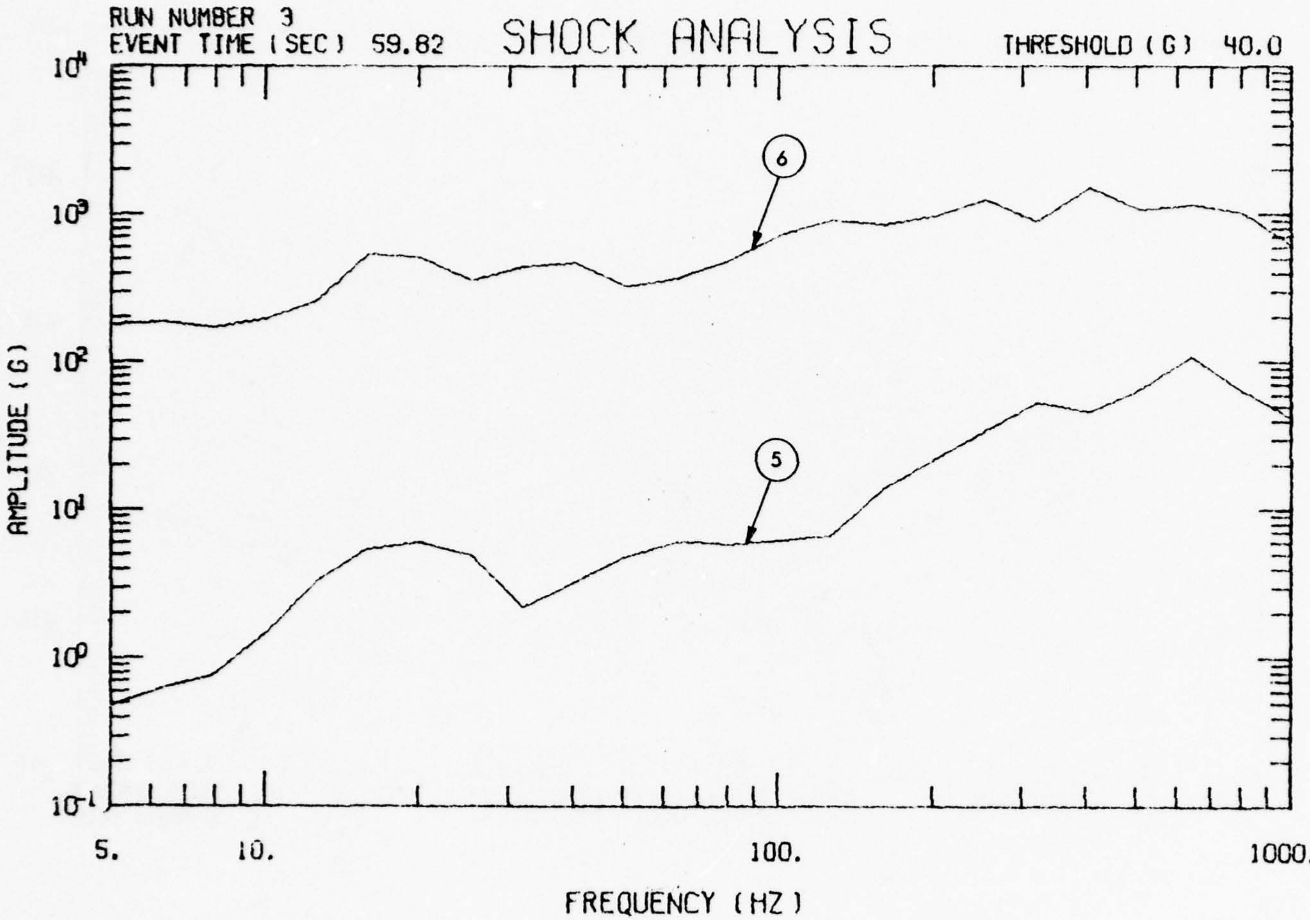
292-531

253

255

14

12.27



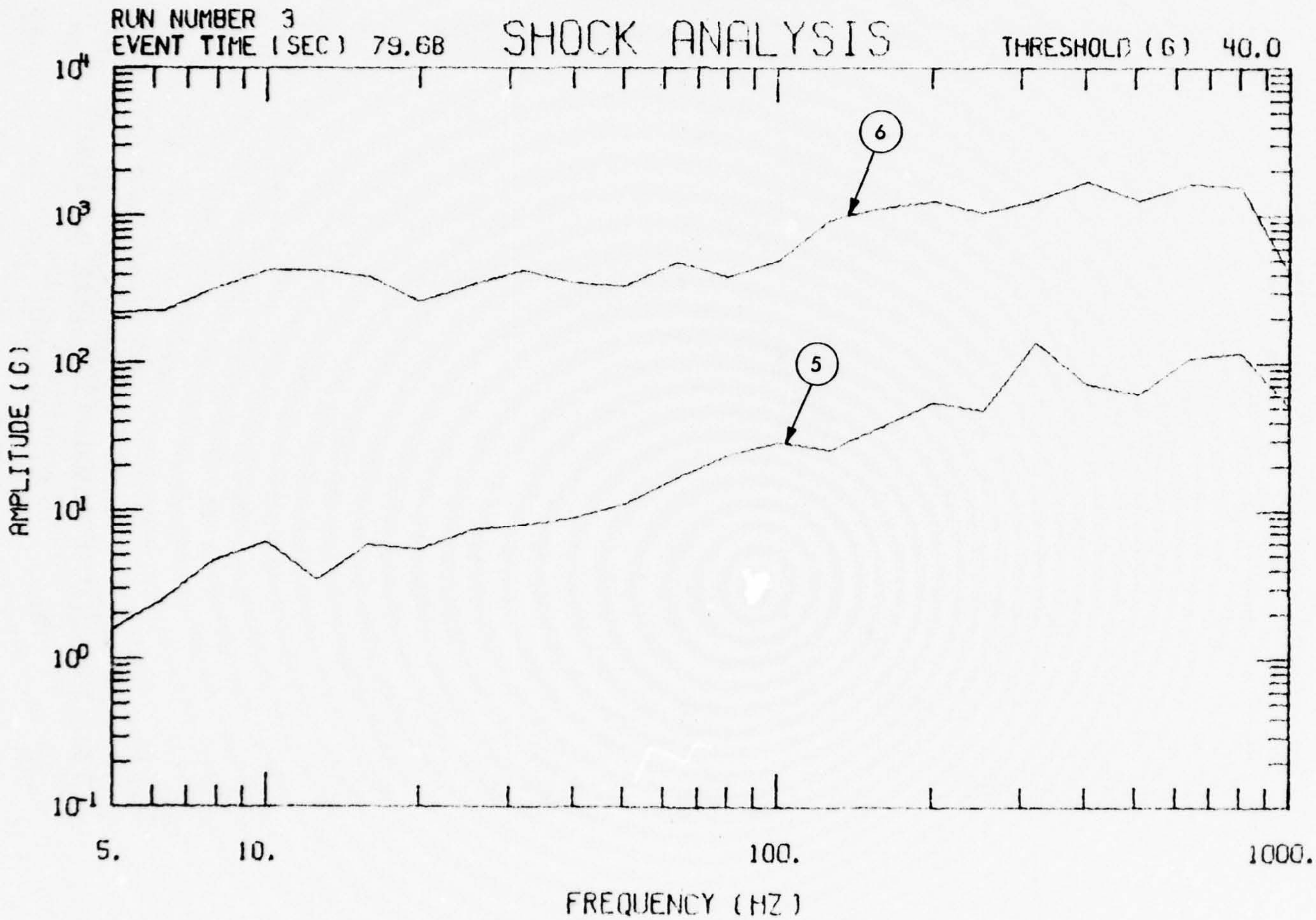
292-531

254

16 12-27

256

260

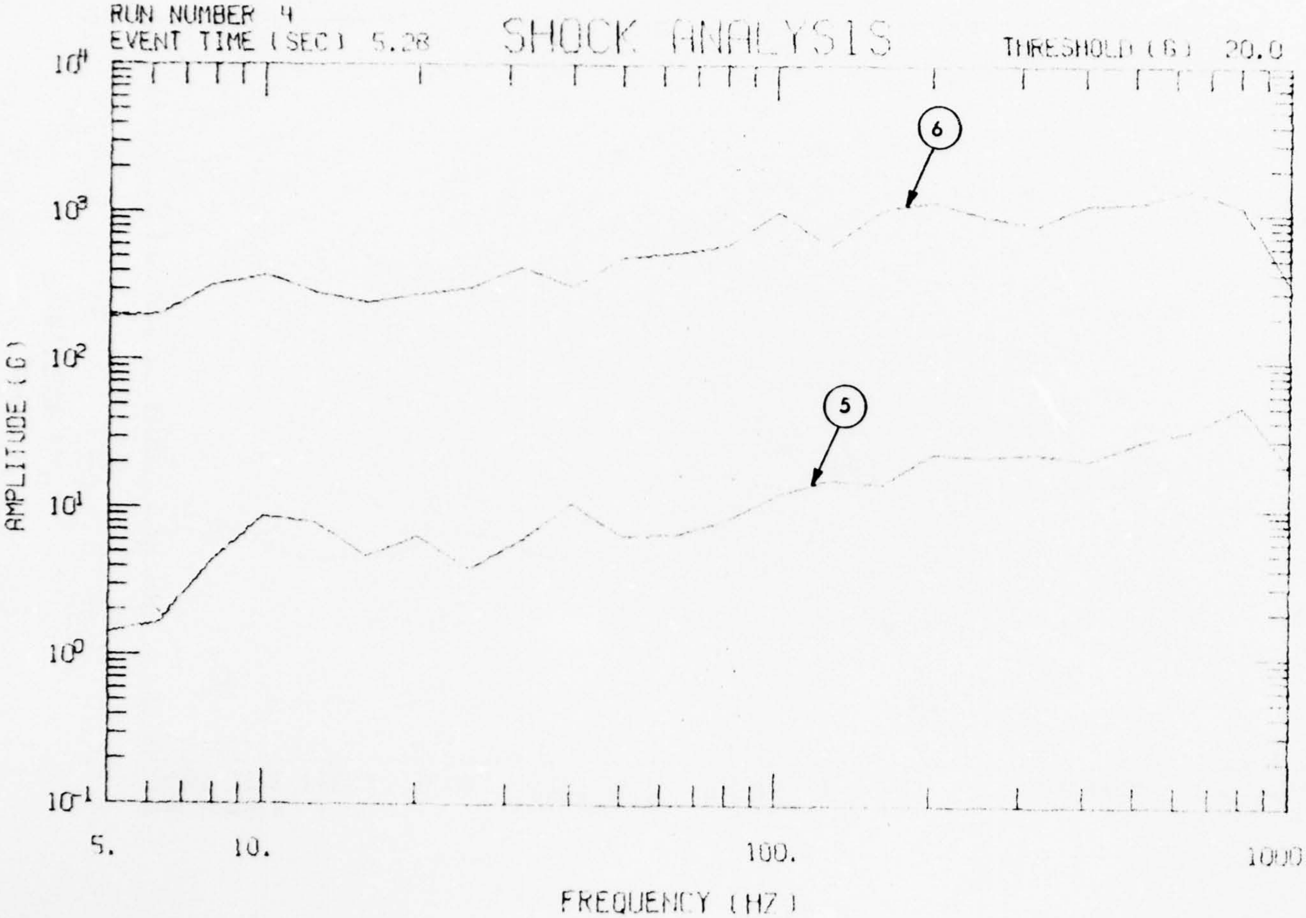


292-531

255

17

12-27

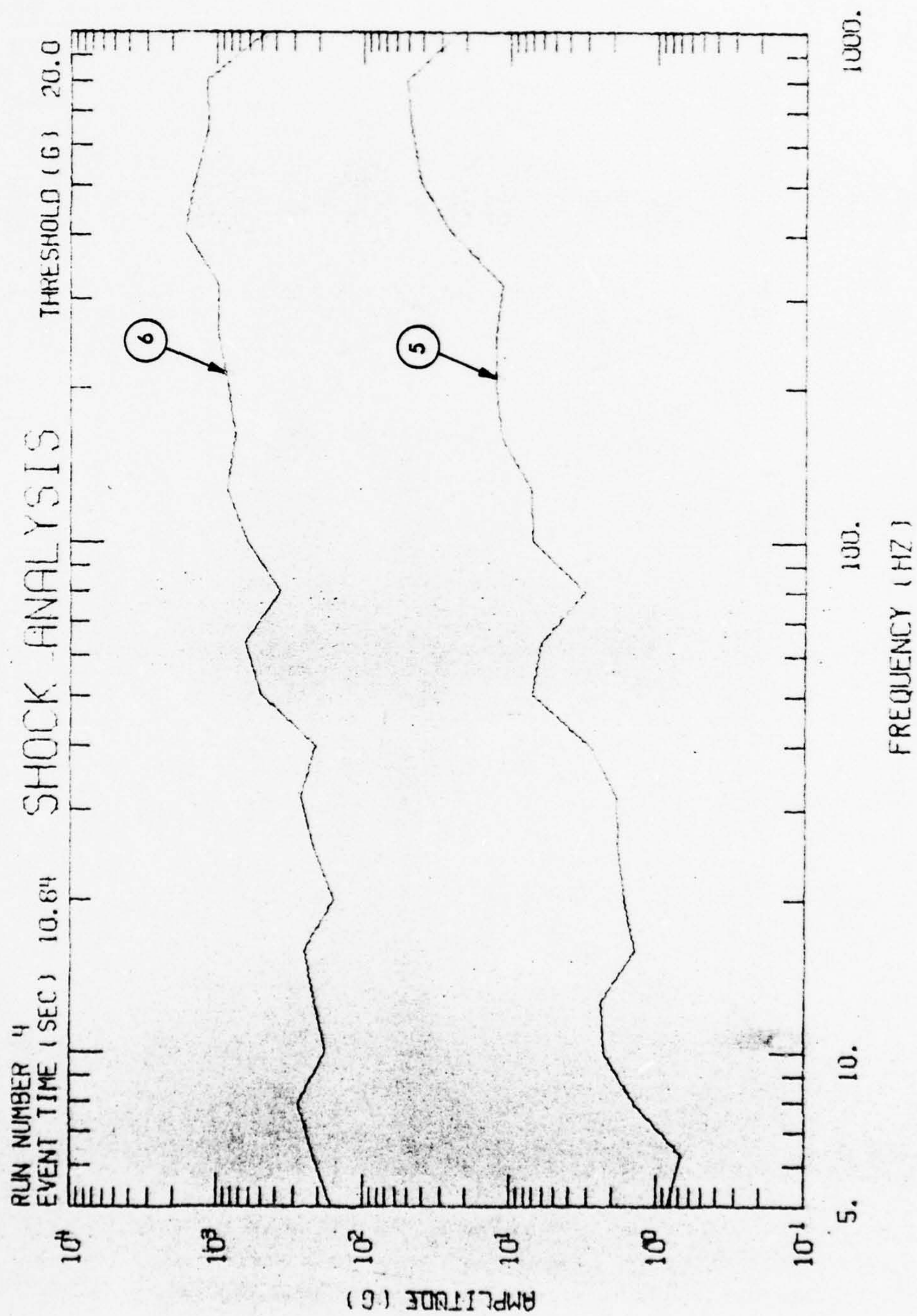


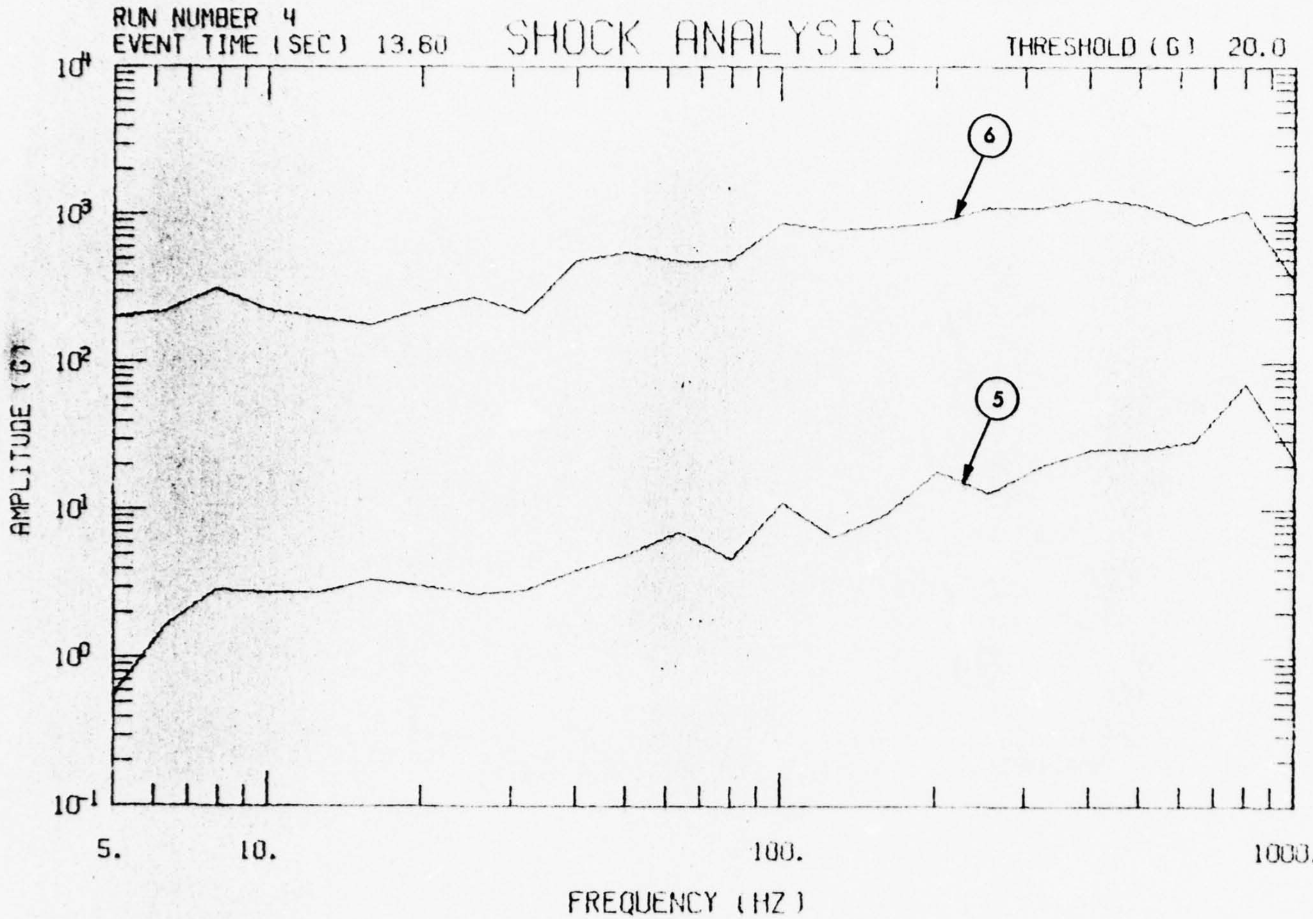
20

292-531

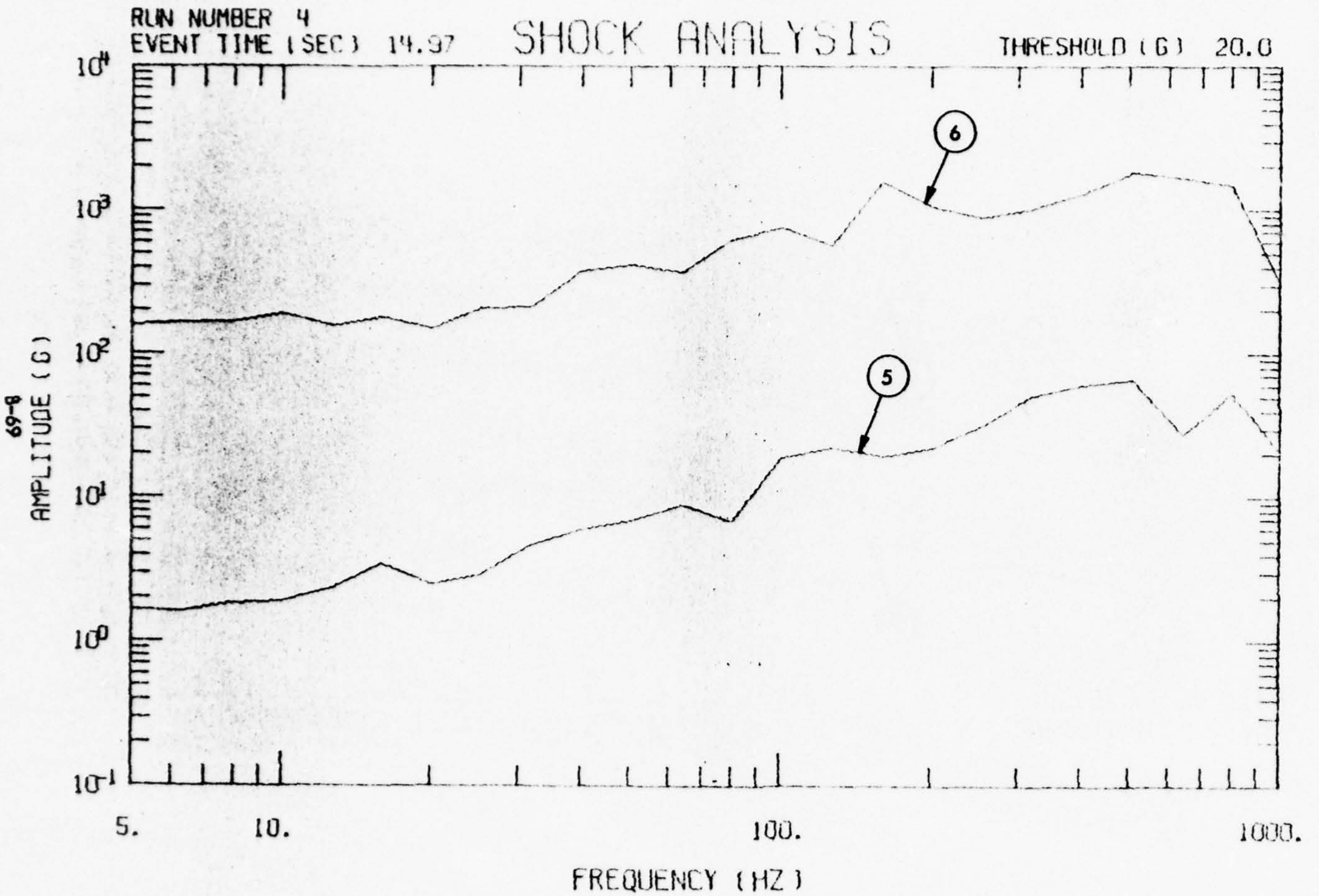
256

258


RUN NUMBER 4
EVENT TIME (SEC) 10.84
SHOCK ANALYSIS
THRESHOLD (G) 20.0
6
5
AMPLITUDE (G)
FREQUENCY (HZ)
10⁴
10³
10²
10¹
10⁰
10⁻¹
5.
10.
100.
1000.


RUN NUMBER 4
EVENT TIME (SEC) 13.60
SHOCK ANALYSIS
THRESHOLD (G) 20.0
AMPLITUDE (G)
FREQUENCY (HZ)
6
5

22

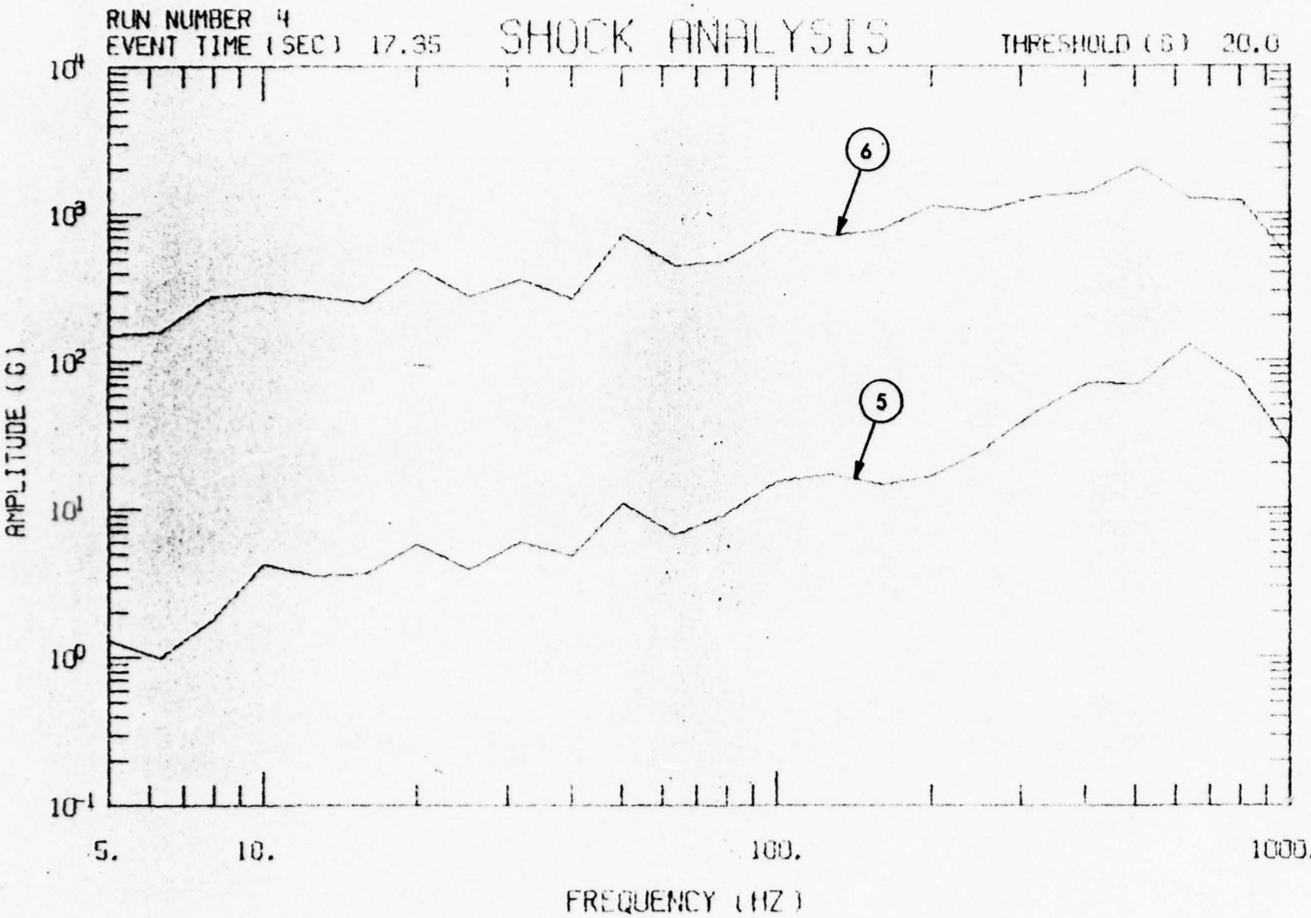


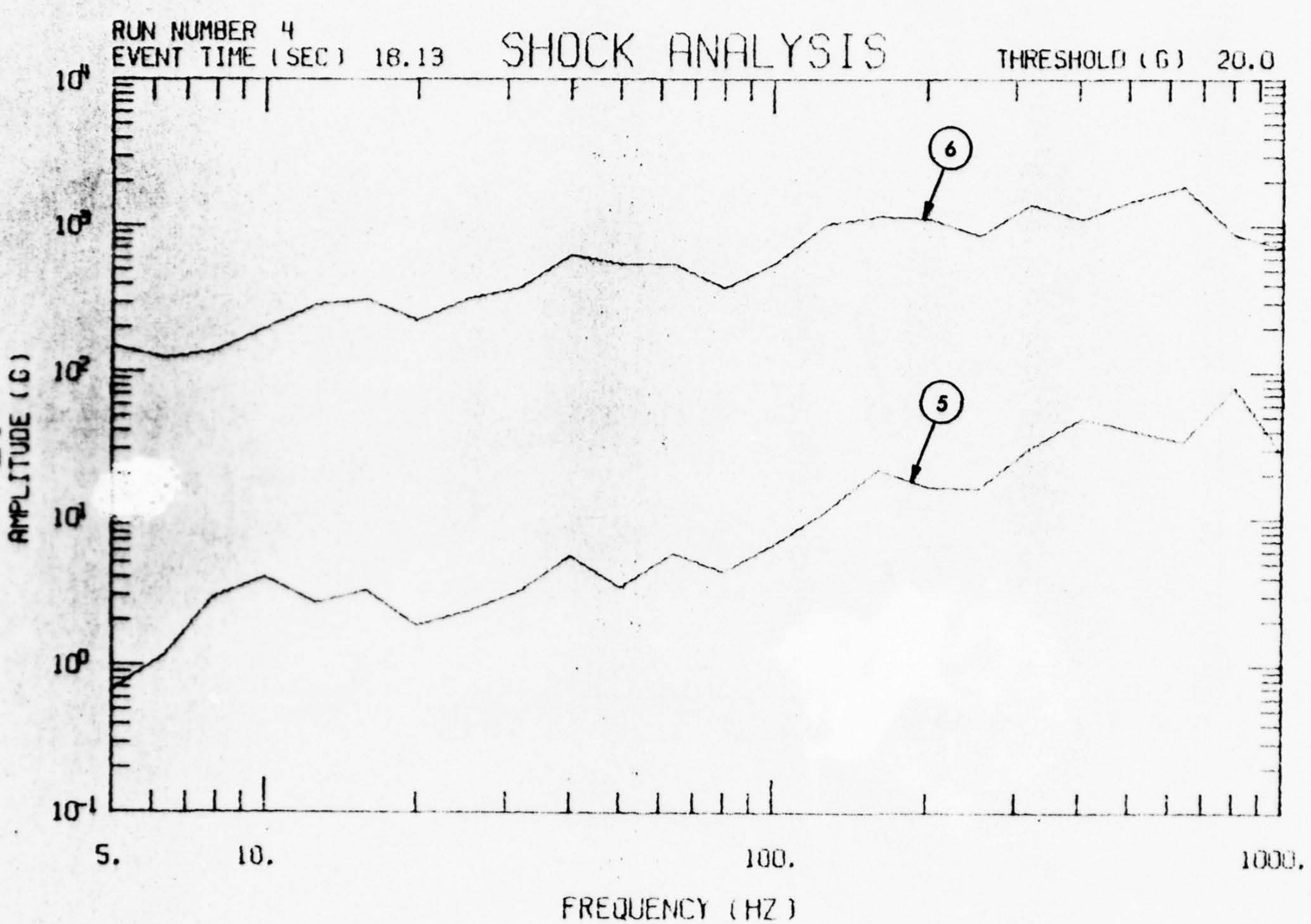
B-69

292-531 259

261

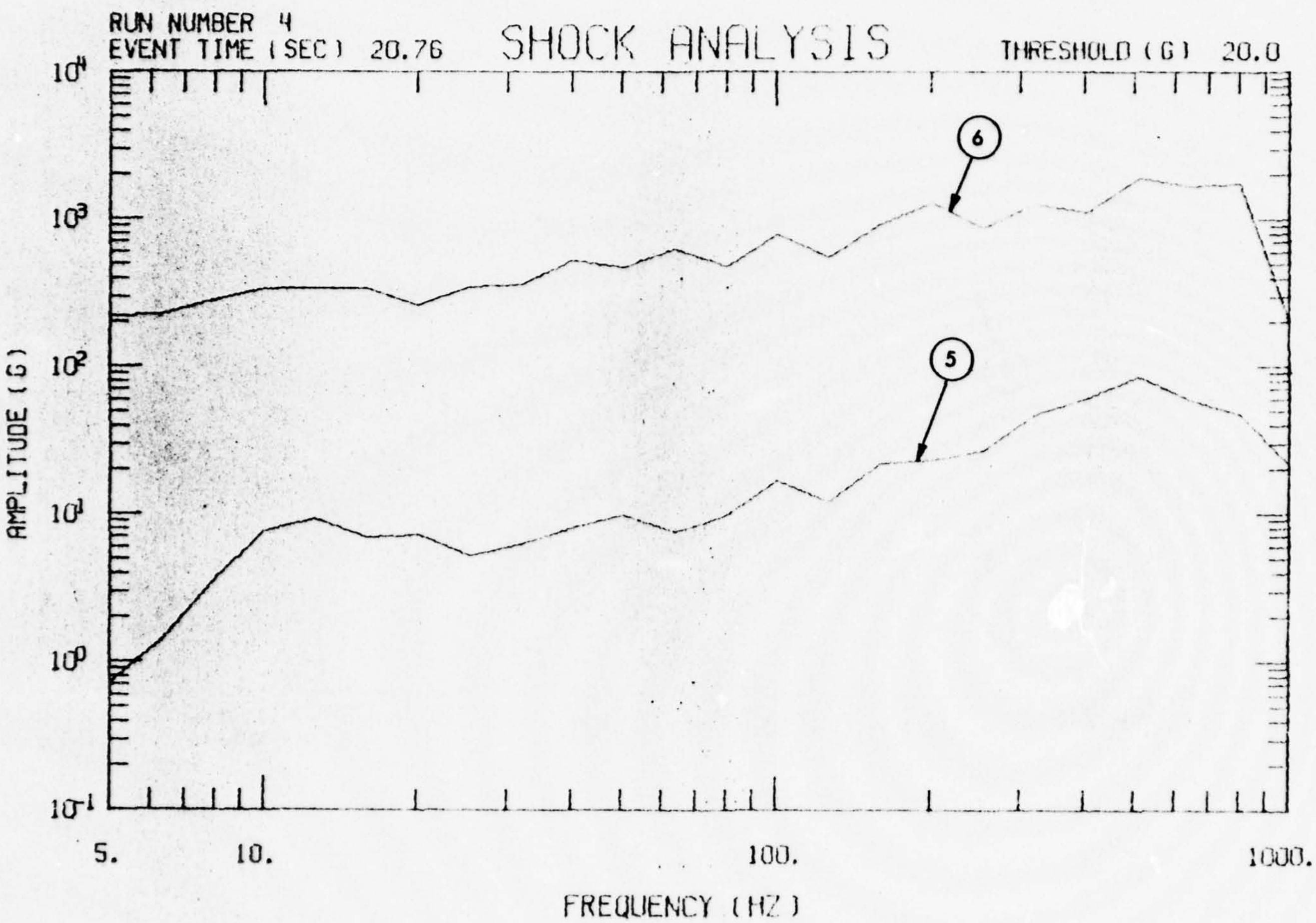
265


RUN NUMBER 4
EVENT TIME (SEC) 17.35
SHOCK ANALYSIS
THRESHOLD (G) 20.0
AMPLITUDE (G)
10^4
10^3
10^2
10^1
10^0
10^{-1}
6
5
5.
10.
100.
1000.
FREQUENCY (HZ)



292-531 261

263 267

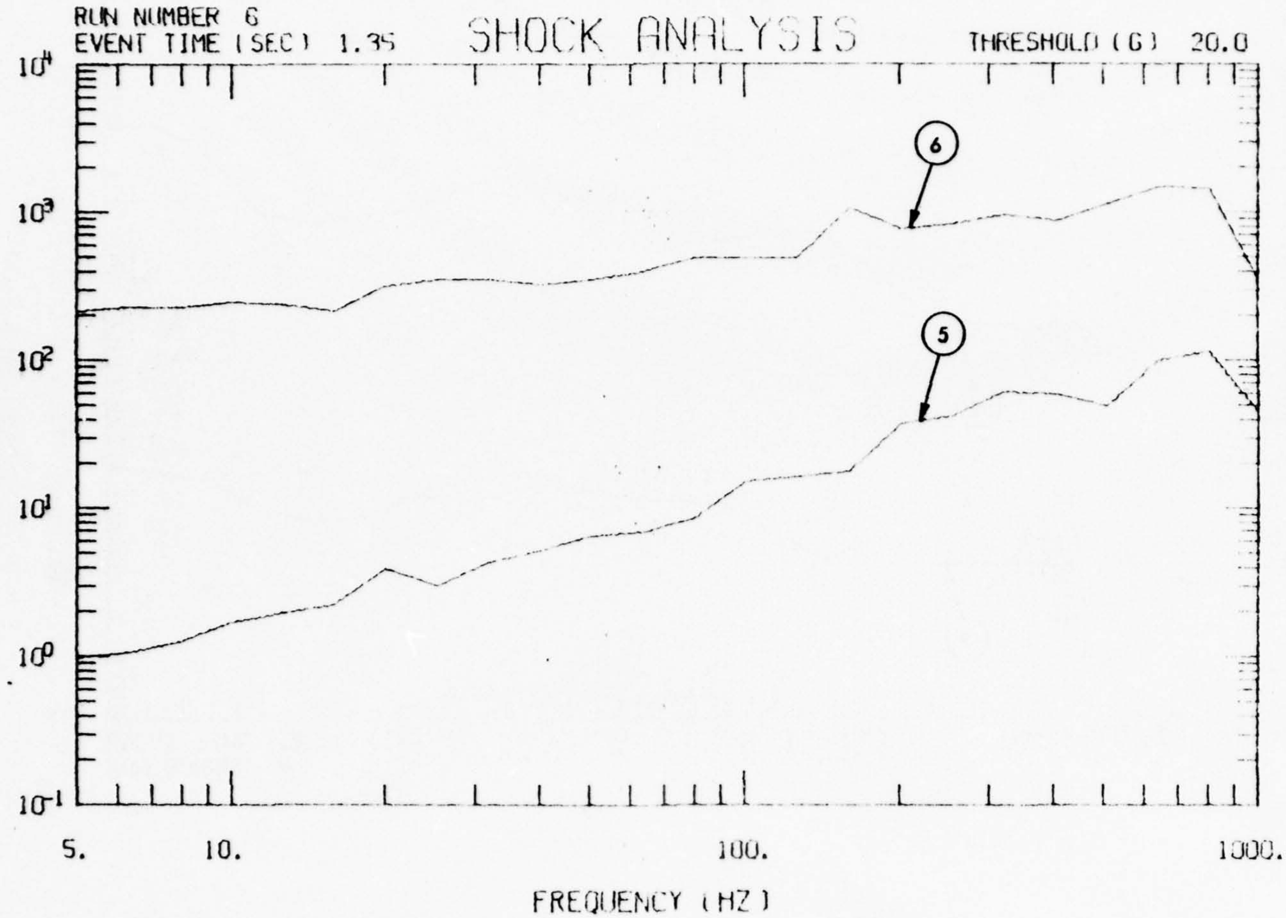


B-72

292-531 (262)

26

(264)

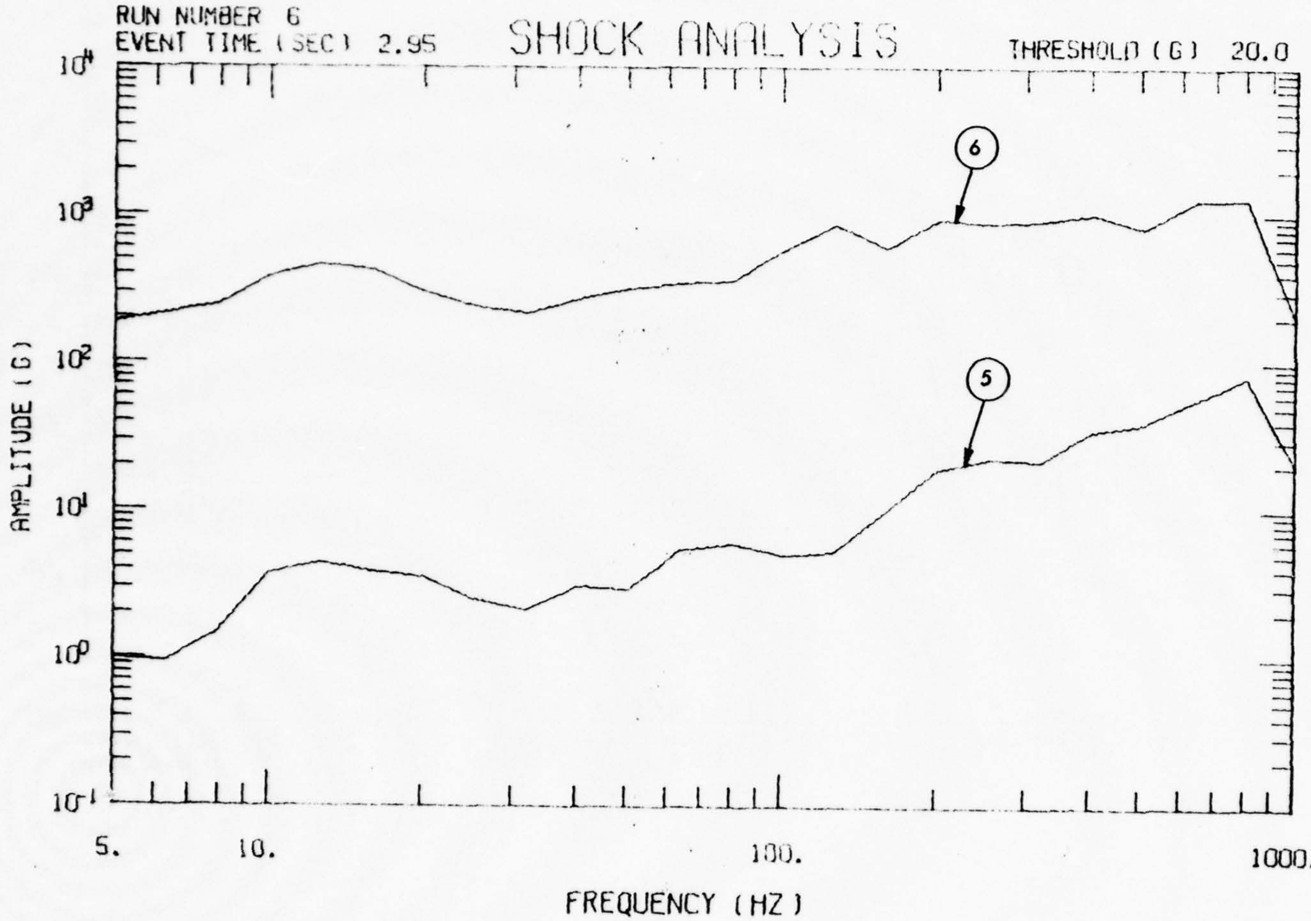


B-73

292-531 263

265

28



B-74

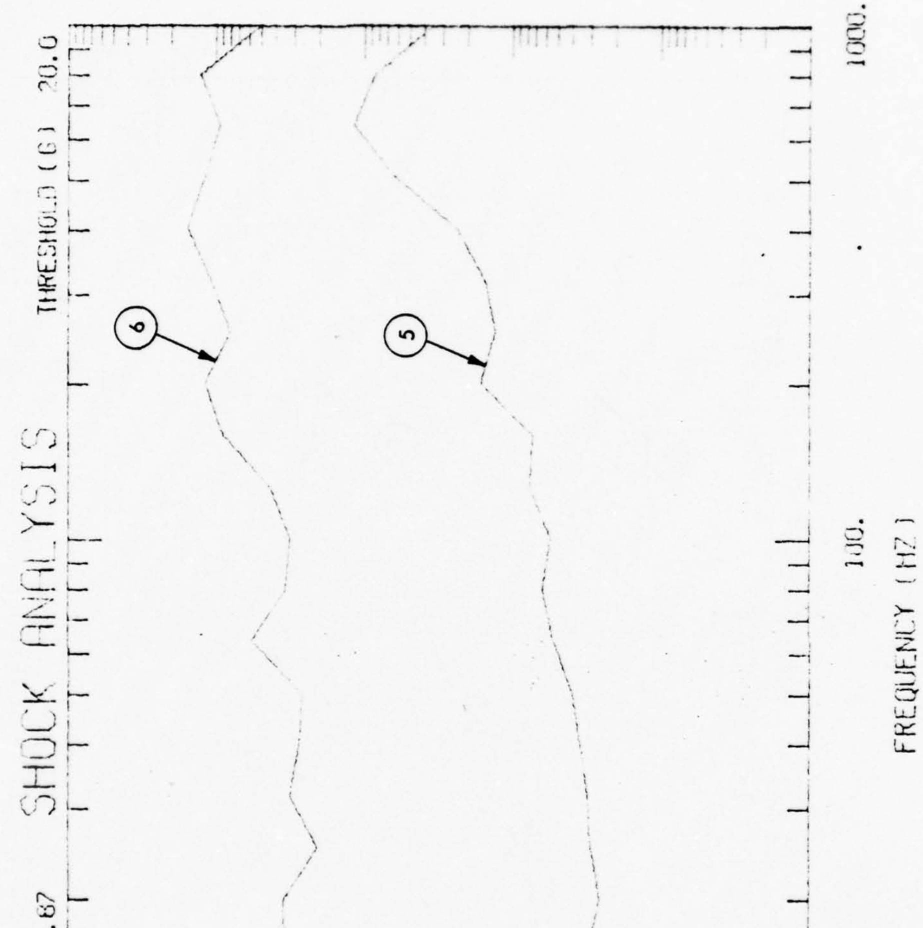
292-531

264

266

270

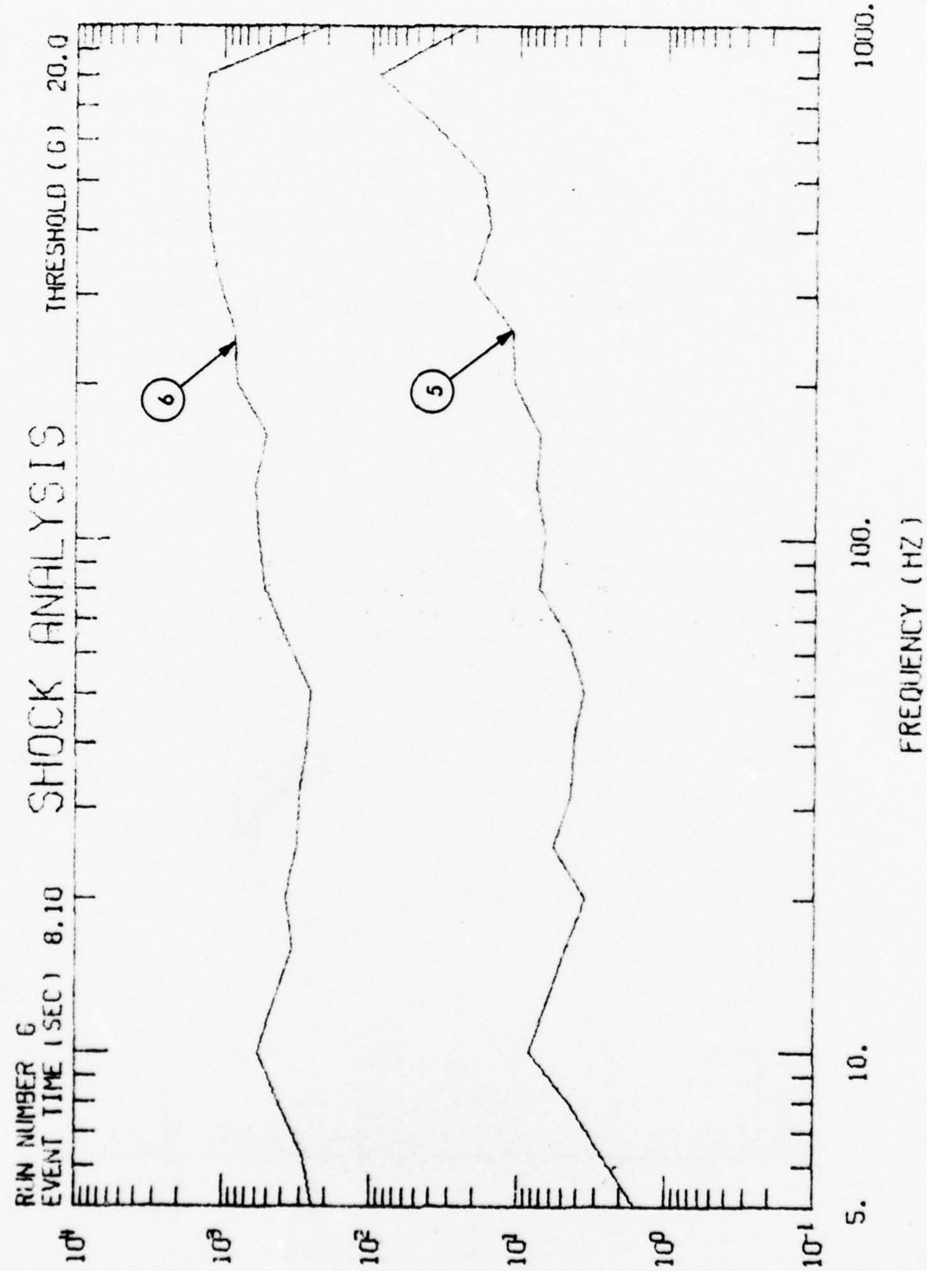
29



292-531 265

267

271



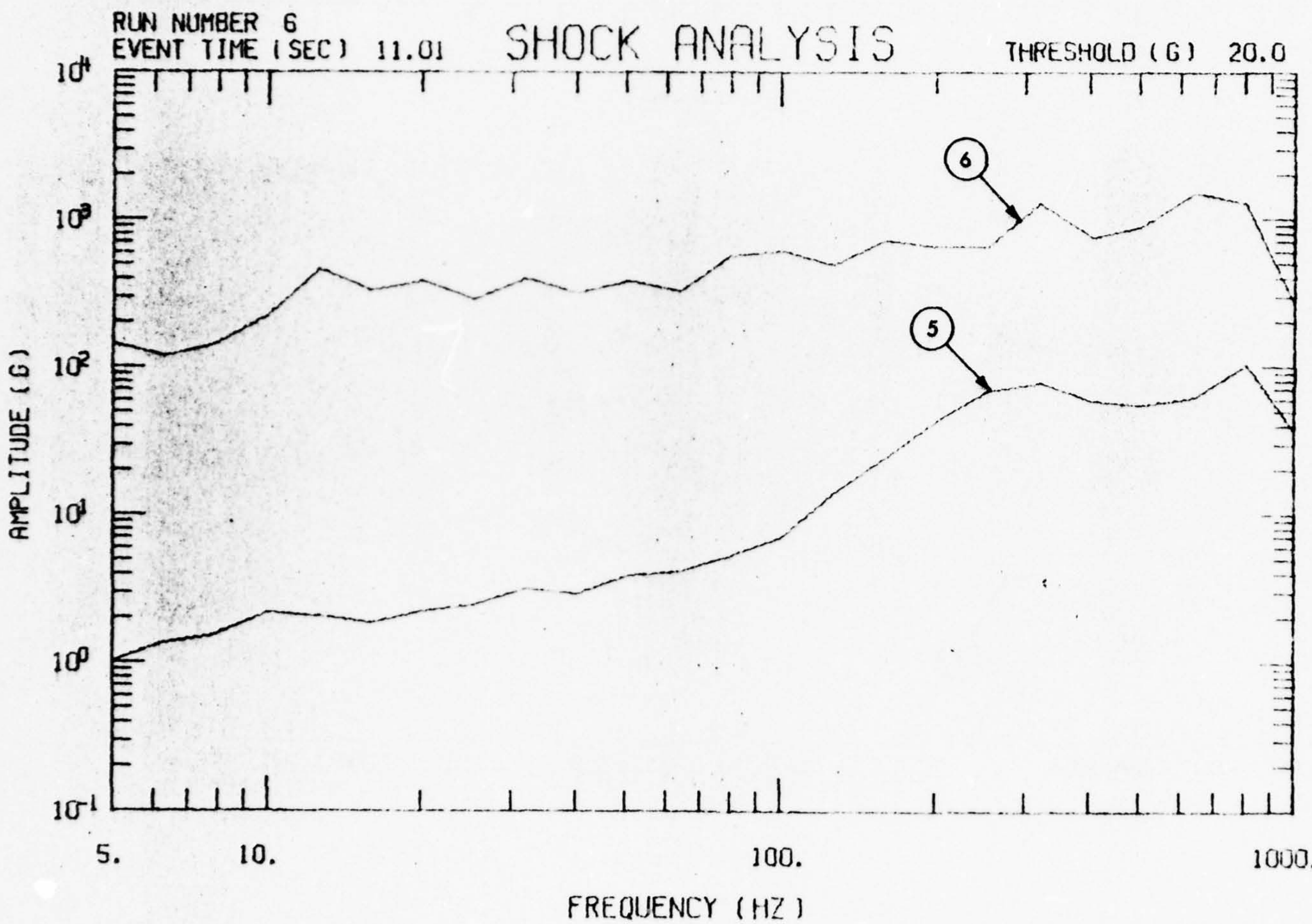
B-76

292-531 (266)

31

268

272

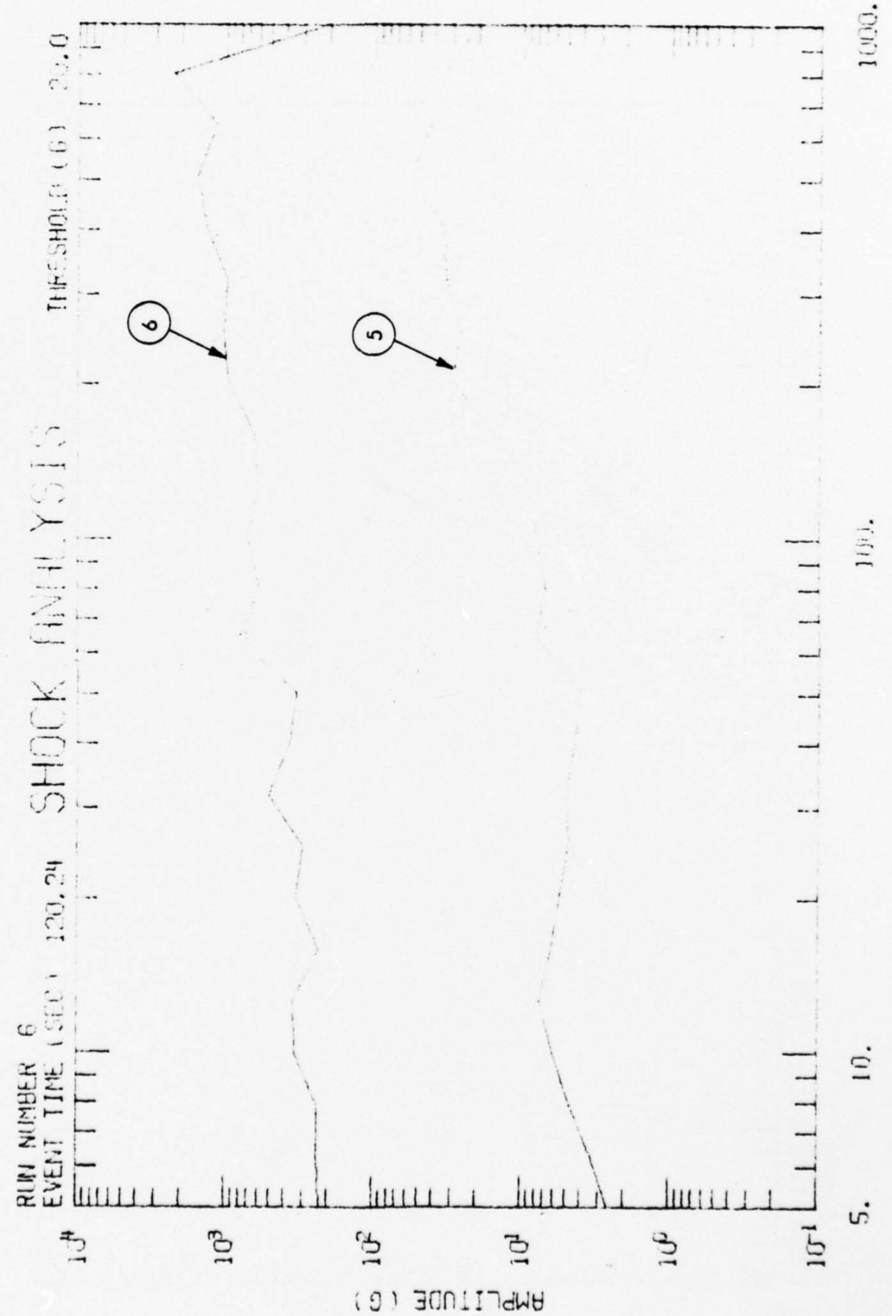

RUN NUMBER 6
EVENT TIME (SEC) 11.01
SHOCK ANALYSIS
THRESHOLD (G) 20.0
AMPLITUDE (G)
FREQUENCY (HZ)
10^4
10^3
10^2
10^1
10^0
10^{-1}
5.
10.
100.
1000.
6
5

269

272

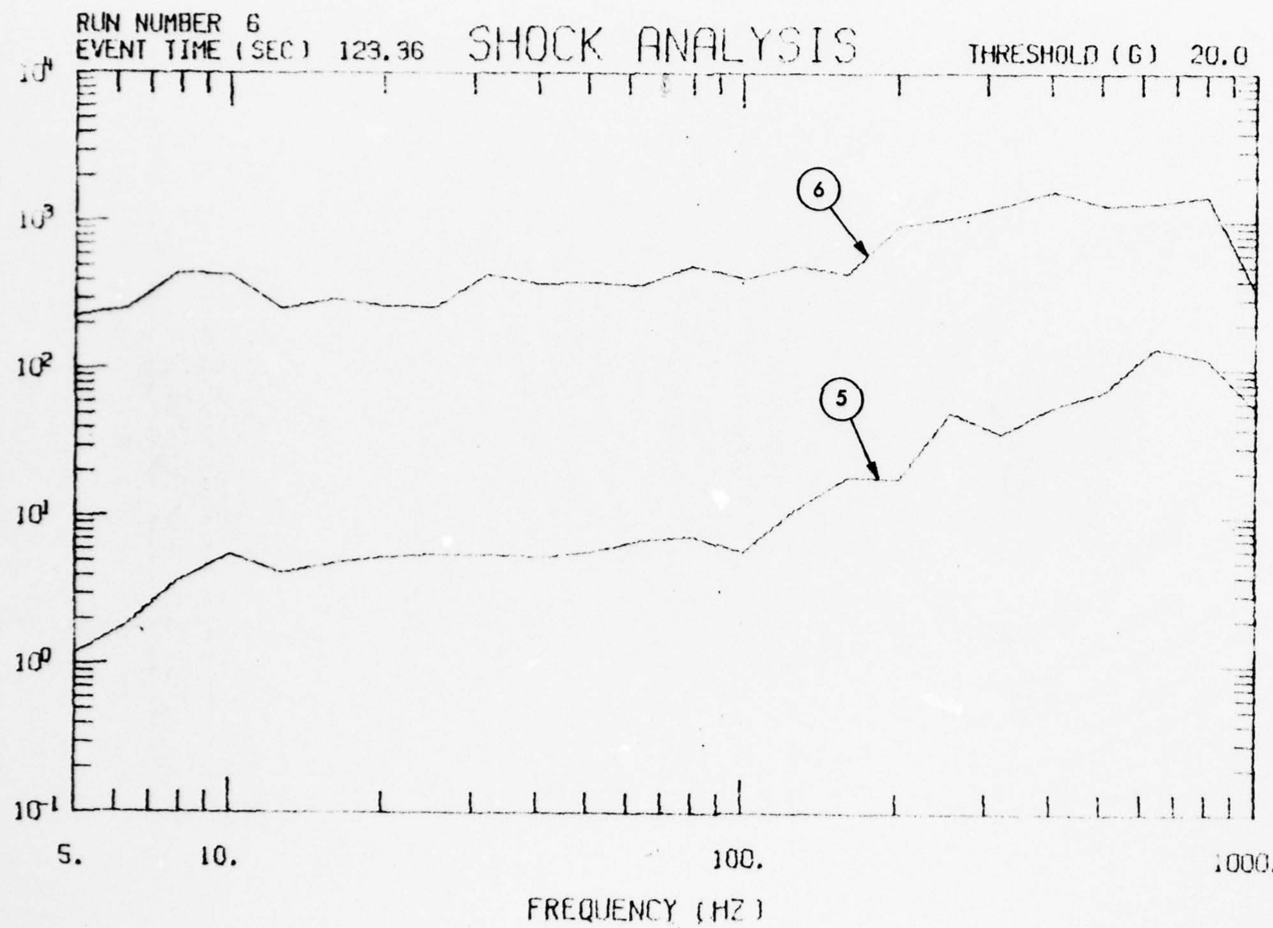
32


RUN NUMBER 6
EVENT TIME (SEC) 117.12
SHOCK ANALYSIS
THRESHOLD (G) 20.0
6
5
AMPLITUDE (G)
10^4
10^3
10^2
10^1
10^0
10^{-1}
5.
10.
100.
1000.
FREQUENCY (HZ)



292-531 269

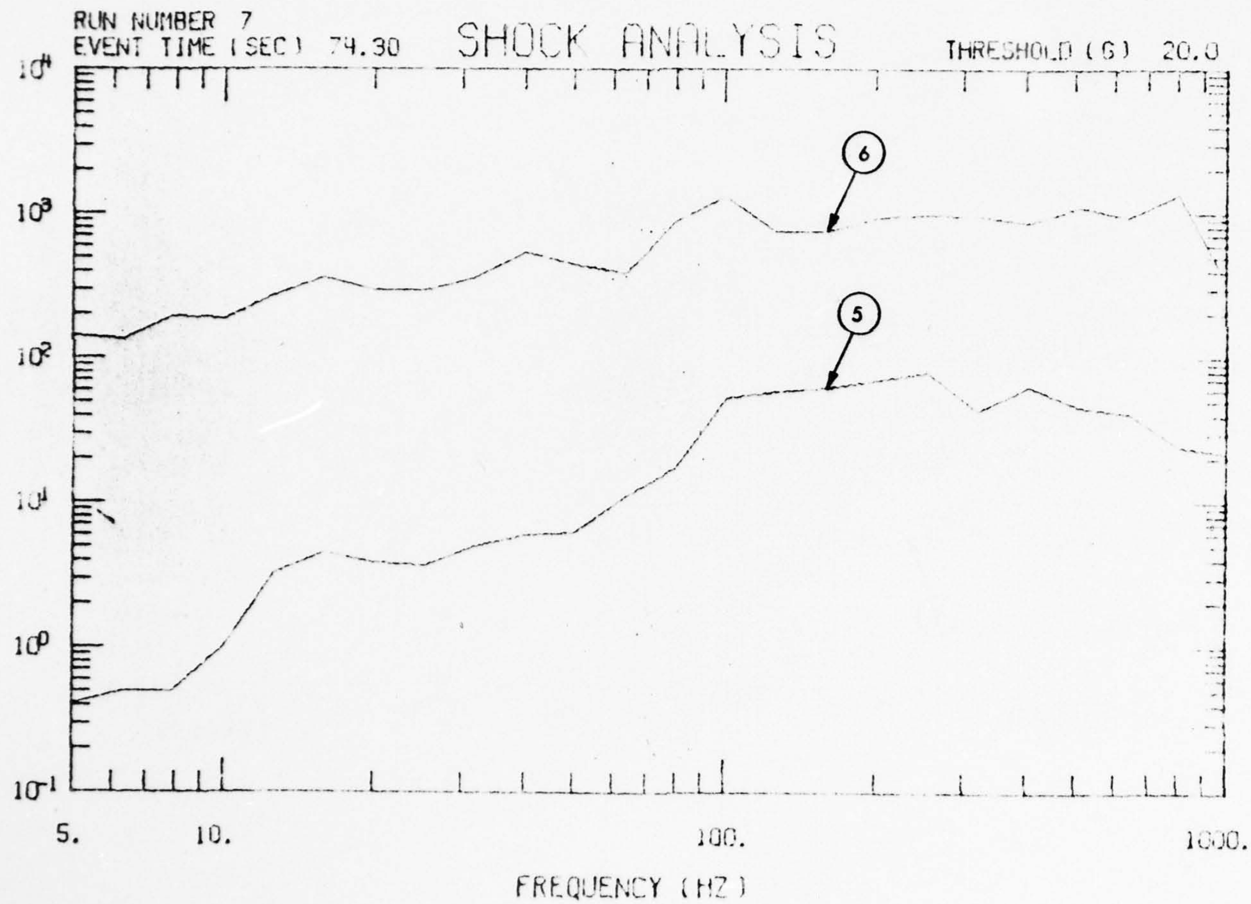
271



8-80

292-531 (270)

272



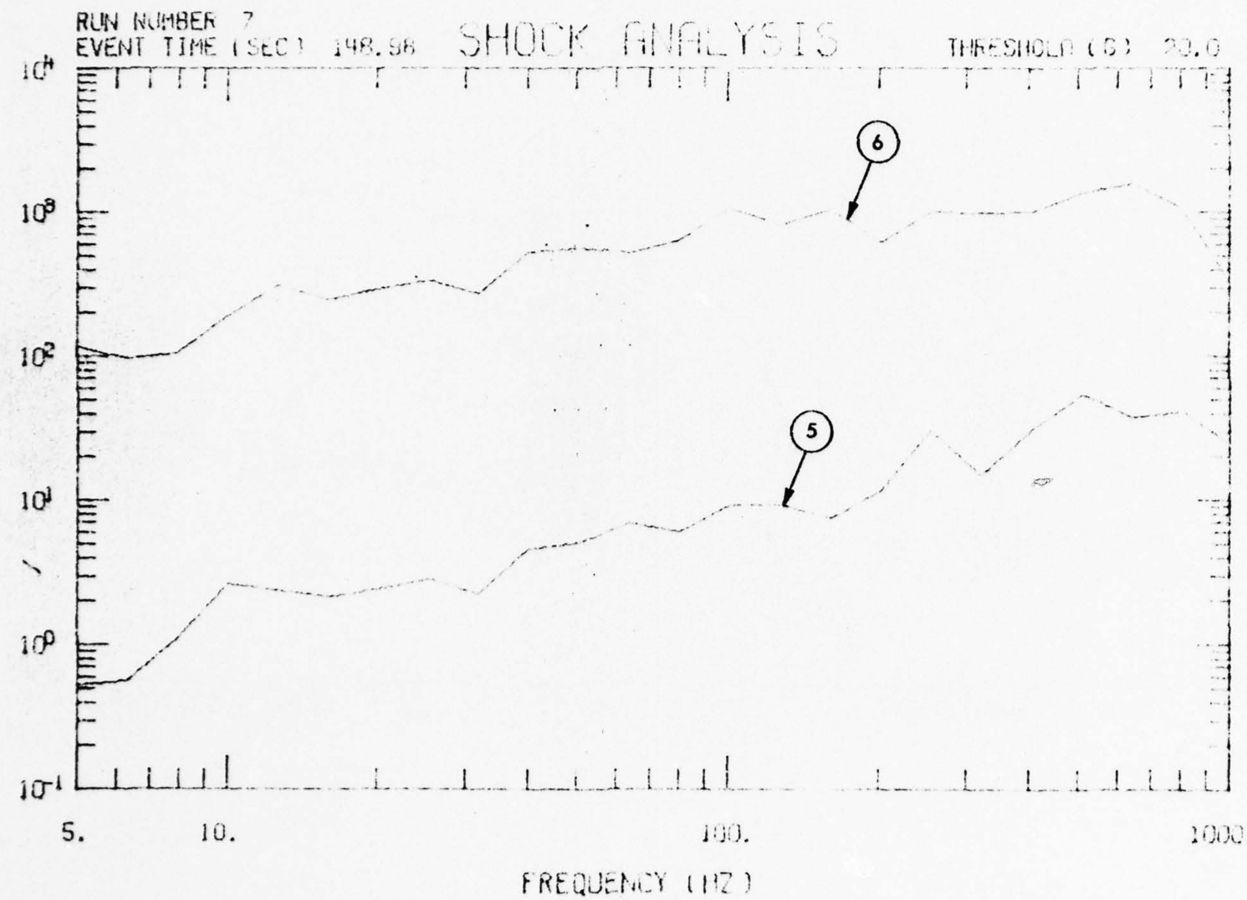
B-81

292-531 271

273

274

37

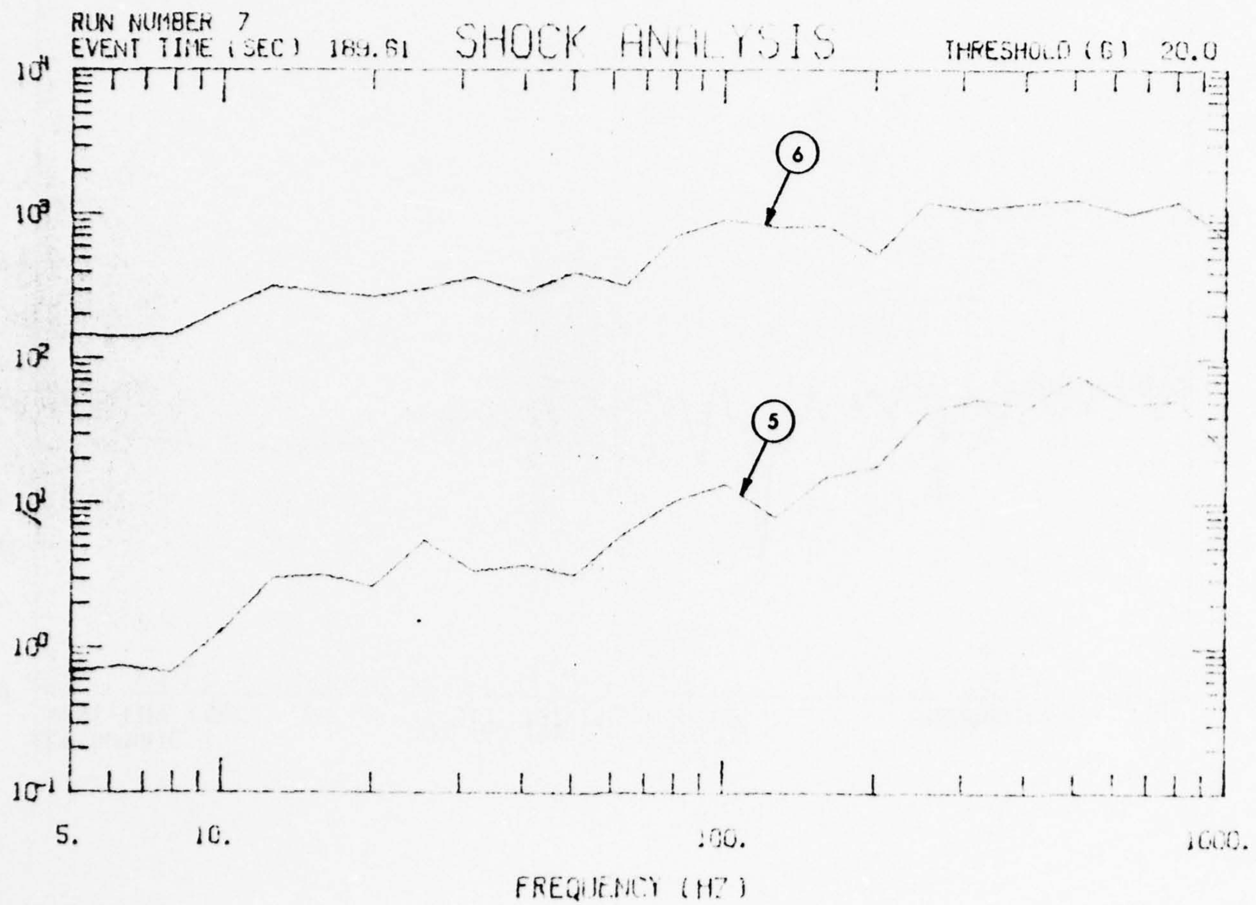


38

B-82

292-531 272

274

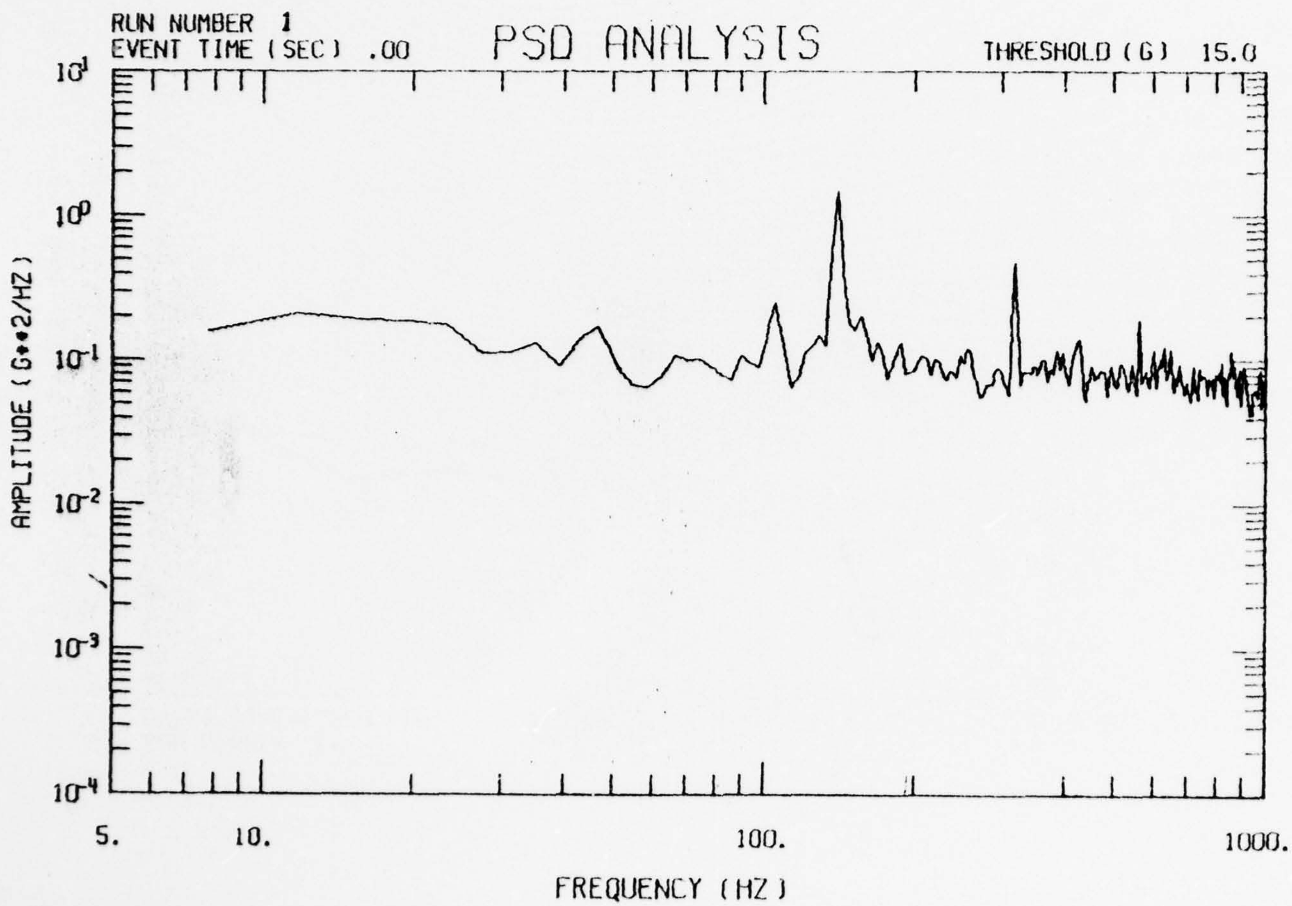


B-83

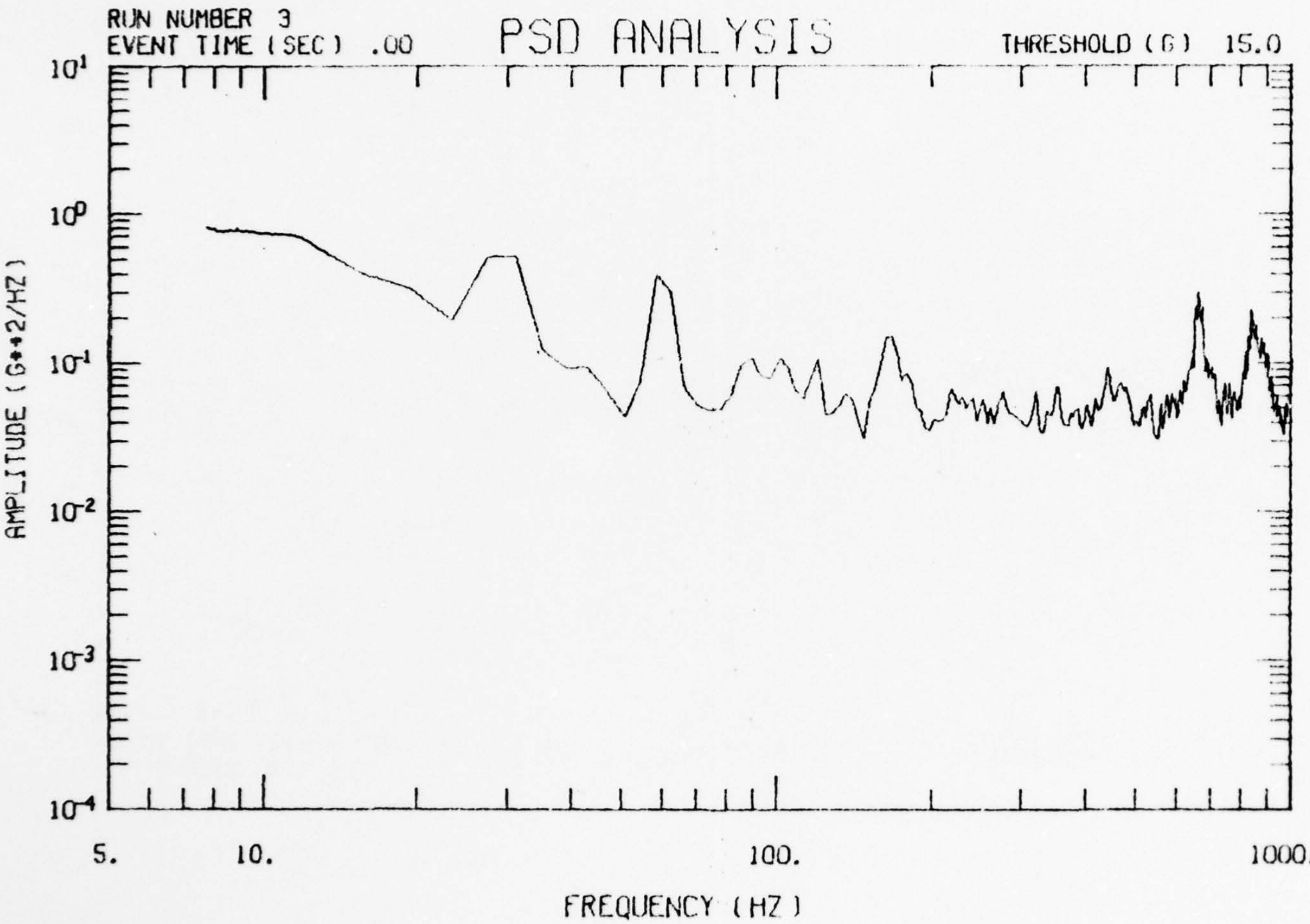
292-531 (273)

275

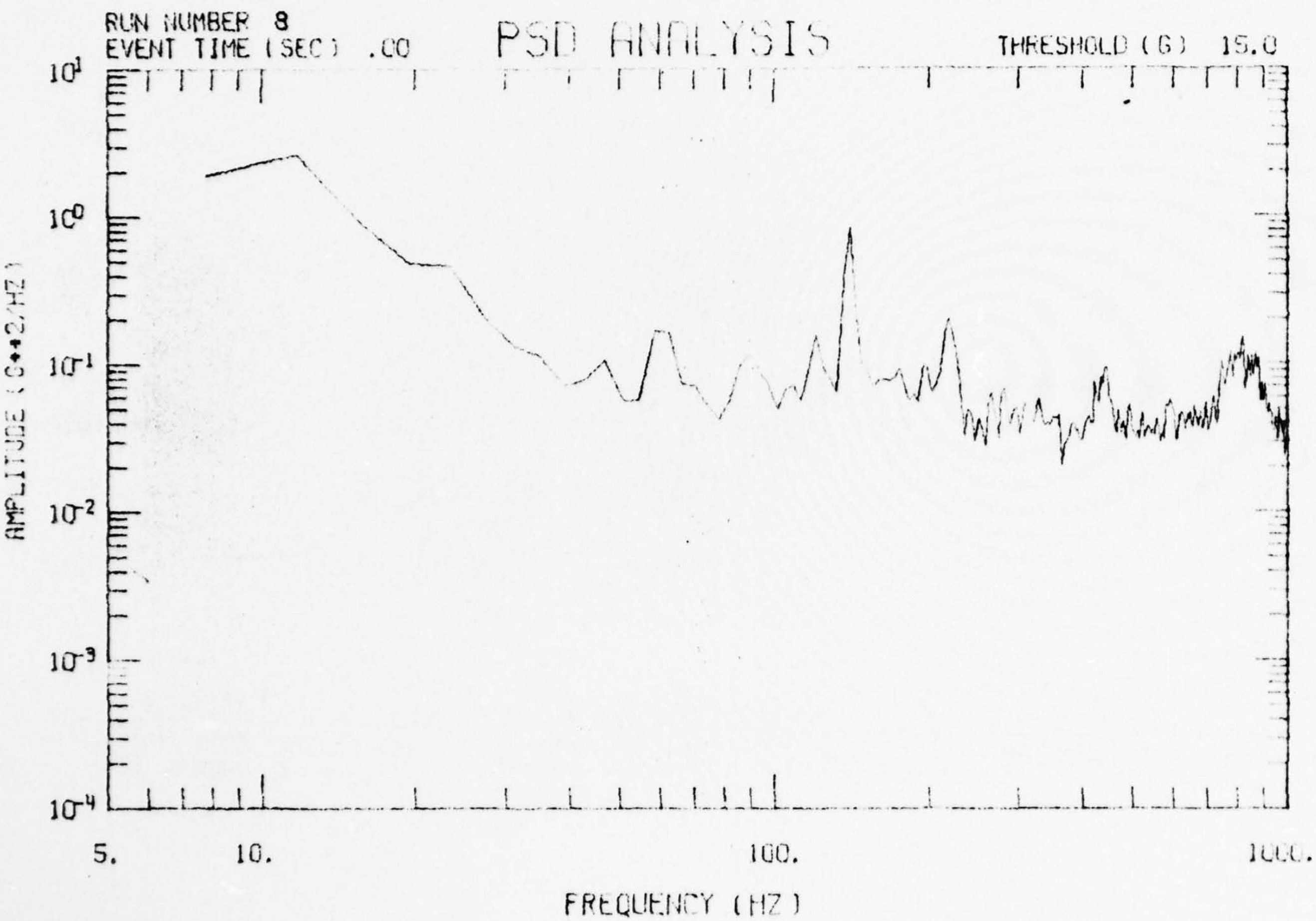
274



RUN NUMBER 1
EVENT TIME (SEC) .00
PSD ANALYSIS
THRESHOLD (G) 15.0
AMPLITUDE (G**2/HZ)
10^1
10^0
10^-1
10^-2
10^-3
10^-4
5.
10.
100.
1000.
FREQUENCY (HZ)


RUN NUMBER 3
EVENT TIME (SEC) .00
PSD ANALYSIS
THRESHOLD (G) 15.0
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
AMPLITUDE (G**2/HZ)
5.
10.
100.
1000.
FREQUENCY (HZ)

292-531 275



B-86

292-531

276

278

APPENDIX C — FAILURE PHYSICS AND ENVIRONMENTAL STRESSORS

At this point in time, the impact of both natural and induced environmental factors on the boat system and its associated subsystems has not been determined. Physics of failure programs over the past 15 years have revealed the many possible mechanisms of failure in different types of parts. The major modes, mechanisms, and activating causes may be summarized as follows:

1. Failure modes

   1. Short circuit
   2. Open circuit
   3. Loss of function
   4. Reduced control
   5. Conductivity change
   6. Arc-over
   7. Structural failure
   8. Stripped gears
   9. Frozen shafts or bearings
   10. Ruptured accumulators
   11. Punctured diaphragms
   12. Broken mounts

2. Mechanisms

   1. Bond failure
   2. Conductor open
   3. Physical wear
   4. Material migration
   5. Material failure
   6. Physical growth
   7. Volumetric absorption
   8. Dielectric rupture
   9. Leakage
   10. Outgassing
   11. Evaporation
   12. Chemical reactions
   13. Corrosion or electrolysis
   14. Crystal structure change
   15. Fatigue rupture
   16. Cold flow

3. Activating causes

   1. Operational stresses
   2. Environmental stresses
   3. Time factors
   4. Emergency operation stress
   5. Mechanical resonance
   6. Flexure fatigue
   7. Contamination and deposits
   8. Foreign inclusions
   9. Maintenance damage
   10. Secondary induced failure

4. Operational stresses

   1. Electric current load
   2. Voltage stress
   3. Induced charges
   4. Transient surges
   5. Radiant energy
   6. Mechanical load
   7. Corona
   8. Checkout stresses
   9. Storage degradation
   10. Surface damage
   11. Mishandling
   12. Forces of nature

5. Environmental stresses

1. Heat
2. Vibration
3. Impact
4. Thermal shock
5. Acceleration
6. Humidity
7. Ambient gases and vapors
8. Pressure
9. Surface deposits

6. Time factors

1. Duty cycle
2. Stress sequence
3. Repetition rate
4. Stress waveform
5. Environmental profile
6. Time degradation

The subject of this document is primarily concerned with the environmental extremes that boat subsystems operate within. Therefore, there is no attempt to discuss failures due to overloading, as in the case of an electrical component, or overstressing a mechanical or structural part or member, as in the case of overstressing an engine. These are areas that manufacturers of marine hardware and electronics should be well aware of and know how to handle successfully. However, it is the area of environmental stressors, in addition to the operational stressors, that must be accounted for in order to design and manufacture sea-worthy equipment.

It is well recognized that the failure rate of equipment, parts, subsystems, and systems is directly proportional to the amount of stress applied. The designer must recognize the level of stress (all sources) and design accordingly. It is for this reason that knowledge of boat subsystem environments is essential.

There are many good sources of failure rate data. The following five sources are indicative of the availability of this type of information:

1. Prediction of Field Reliability for Airborne Electronic Systems. ARINC Research Corporation. Publication No. 203-1-344 (December 31, 1962).
2. Reliability Stress Analysis for Electronic Equipments. MIL-HDBK-217 (December 31, 1961).
3. Earles, D.R. and M.F. Eddins. Failure Rates. AVCO Corporation (April, 1962). (An updated version appears in Proceedings, Ninth National Symposium on Reliability and Quality Control (January, 1963).)

4. Bureau of Naval Weapons Failure Rate Data Handbook. U.S. Naval Ordnance Laboratory. Corona, California. (Available only to qualified contractors and government agencies.)

5. Reliability Prediction and Measurement of Shipboard Electronic Equipments. Vitro Corporation. Report No. 98 (April 15, 1957).

Failure rate data is compiled from various sources where the item, component, or part (or parts of the same type) has been used. It is then "stripped," so to speak, of its stressor effects. This data is normally referred to as the generic failure rate. When a population of items is exposed to operation under a nominal rating, it exhibits the nominal or generic failure rate. If the operating stress level is increased, the failure rate increases. If the operating stress level is decreased, the failure rate decreases. There is not, however, necessarily a direct correlation between the two and there are, of course, exceptions to the rule. Figure C-1 illustrates the effect of a constant stress level applied to the classic failure rate bathtub curve.

K_A and K_E represent modifiers of the generic failure rate for what is known as application stresses and environmental stresses. Application stresses are the stresses created by the manner of applying an item in a system (mechanical or electrical) for the direct accomplishment of an operation function. Environmental stresses (or stressors) are the stresses induced in an item due to operation in a surrounding environment.

A component, part, item, or system fails when stress conditions or individual stresses exceed its strength. In most component lots, there are a few initially weak, substandard specimens that will naturally fail at much lower stress levels than the rest. The mechanism of early failure is the unpredictable sudden stress levels and accumulations external and internal to the component beyond the component design strength. Because of deterioration of strength with time or cycling, there is an increase in failure rate (generally at an exponential rate of increase) in what is commonly called the wear-out period (see Figure C-2).

A designer of shipboard equipment (components, parts, subsystems) can utilize the failure rate data available to determine whether his design will sustain the environmental stressor extremes or to what level of stressor or stressors it can be expected to survive. For this type of equipment, the main stressors will be shock/vibration, heat, and humidity. The design engineer would

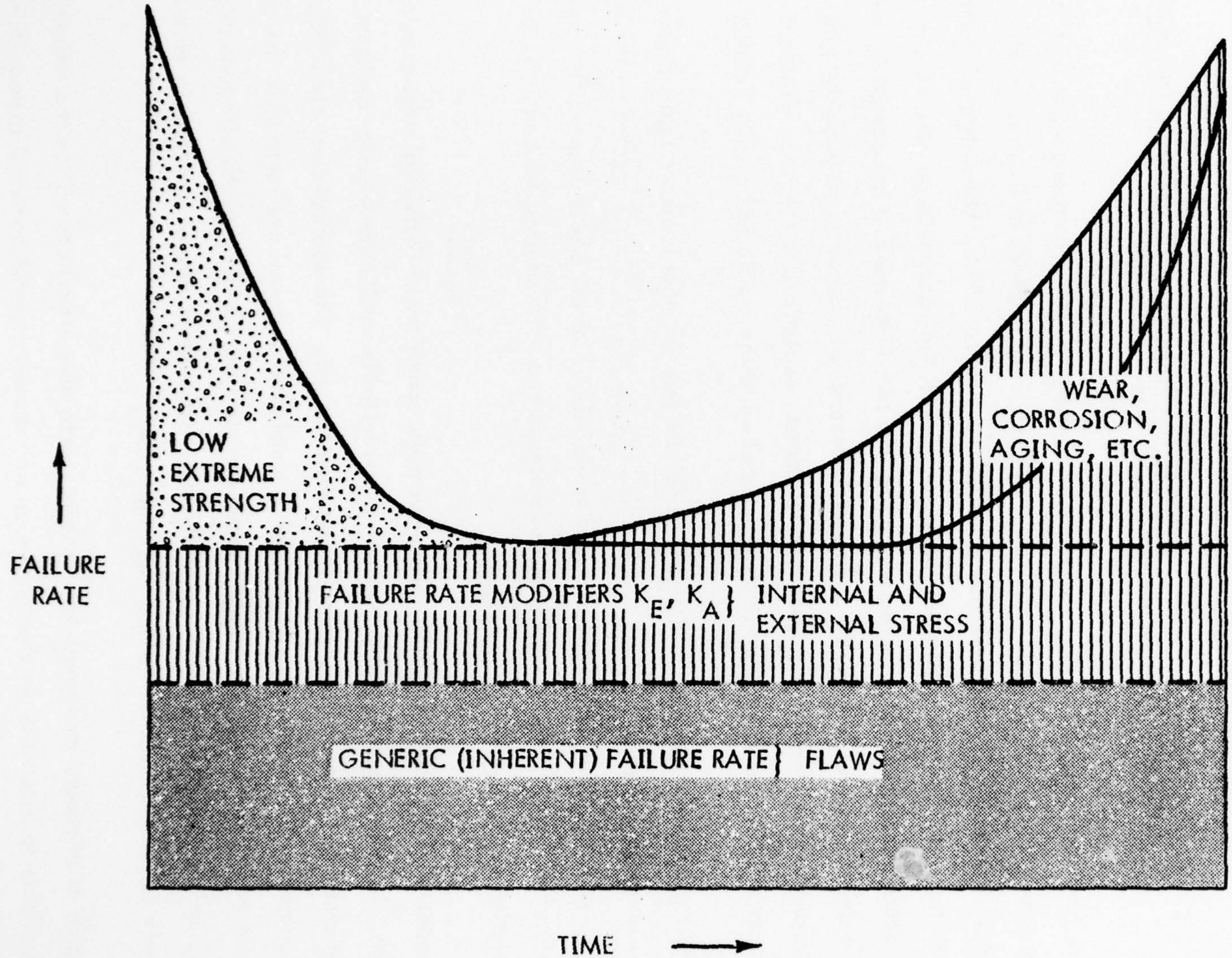


FIGURE C-1. STRESSED FAILURE RATE AS A FUNCTION OF TIME

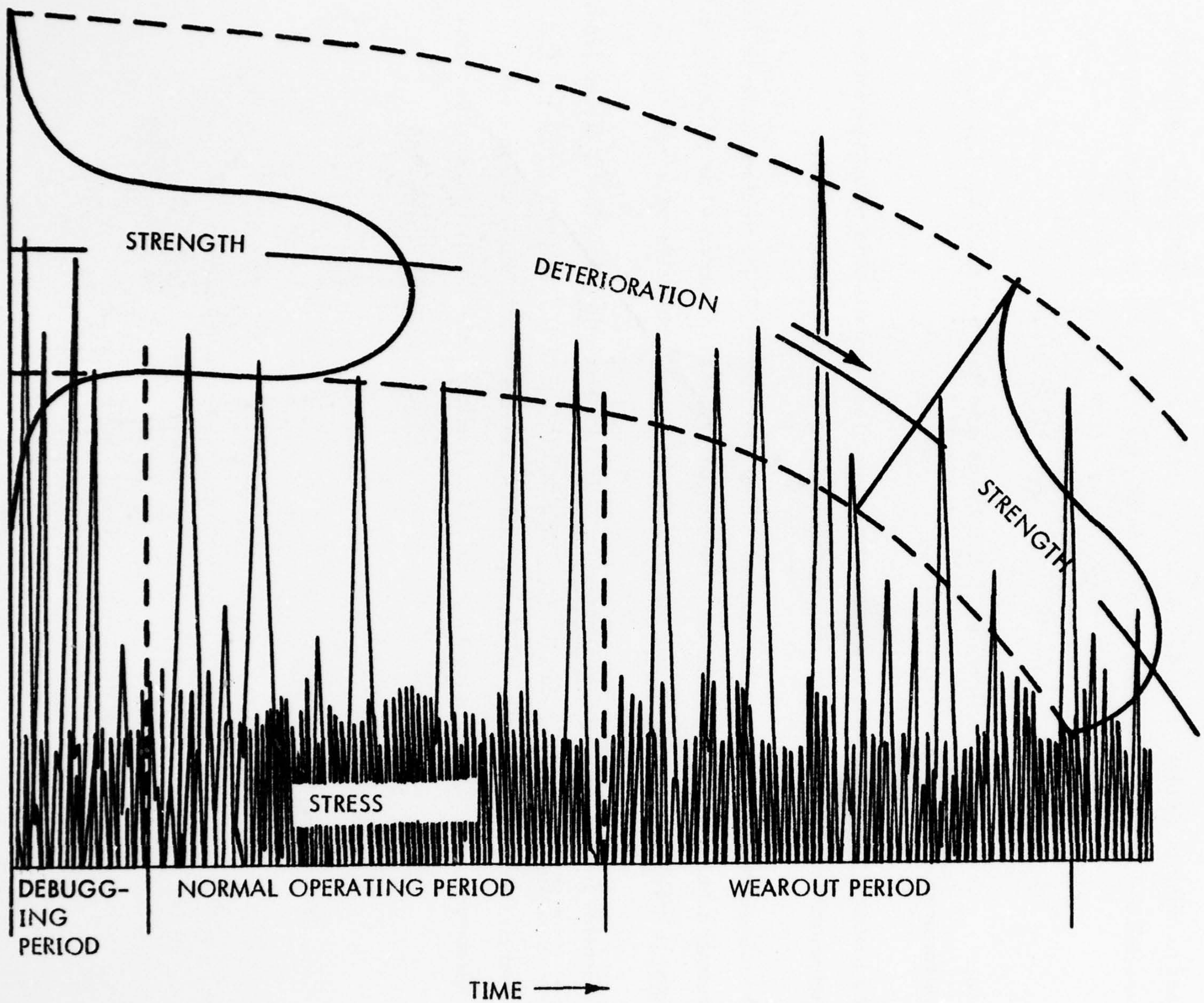


FIGURE C-2. STRENGTH VERSUS STRESS OVER TIME

need to adjust or correct the generic failure rate for the stressors the component would be expected to face. The correction factors generally take the form of an equation similar to:

$$\lambda_A = \lambda_G \cdot \left(K_1 \cdot K_2 \cdot K_3 \cdots\cdots K_n\right)$$

where λ_A is the adjusted failure rate, λ_G is the generic failure rate and K_1, K_2, K_3 ... K_n are correction factors for various stressors.

The literature pertaining to failure rates, previously cited, contains some adjustment factors that would have applicability to any industry, boat industry being no exception.

The subsystems environment testing program, while not a true reliability problem, none the less presents a "quasi-reliability" problem. The program described in Section VI for retrieving test data, if implemented, could enable the derivation of directly applicable adjustment factors.

A General Electric document (Information for Reliability Prediction, Revision 1, 30 Sep 1964, ASD-R-05-64-2) presented a concept for synergistically combining various environments that affect an item into one factor. While the concept presented is only applicable to space vehicle environments, a similar matrix could be derived for the boat system/subsystems environments.

CG-D-20-79 - DEFINITION AND CLASSIFICATION OF NATURAL AND INDUCED ENVIRONMENTS OF SOME RECREATIONAL BOATS - SEP 1978

S/S copy for BACKSTRIP
spine
292-531
contractor to adjust